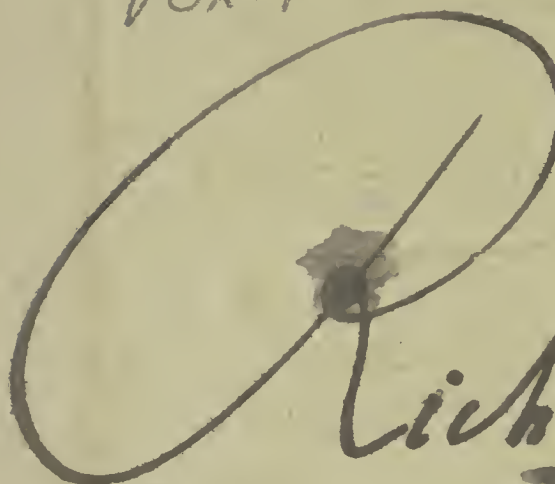




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Vol. 1





THE ECONOMY  
OF  
THE ANIMAL KINGDOM.

LONDON :

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A. S. 1

THE  
ECONOMY  
OF THE  
ANIMAL KINGDOM,



CONSIDERED  
ANATOMICALLY, PHYSICALLY, AND PHILOSOPHICALLY.

BY  
EMANUEL SWEDENBORG,

LATE MEMBER OF THE HOUSE OF NOBLES IN THE ROYAL DIET OF SWEDEN,  
ASSESSOR OF THE ROYAL METALLIC COLLEGE OF SWEDEN,  
FELLOW OF THE ROYAL ACADEMY OF SCIENCES OF UPSALA, AND OF THE ROYAL ACADEMY OF SCIENCES  
OF STOCKHOLM,  
CORRESPONDING MEMBER OF THE IMPERIAL ACADEMY OF SCIENCES OF ST. PETERSBURG.

TRANSLATED FROM THE LATIN

BY  
THE REV. AUGUSTUS CLISSOLD, M.A.

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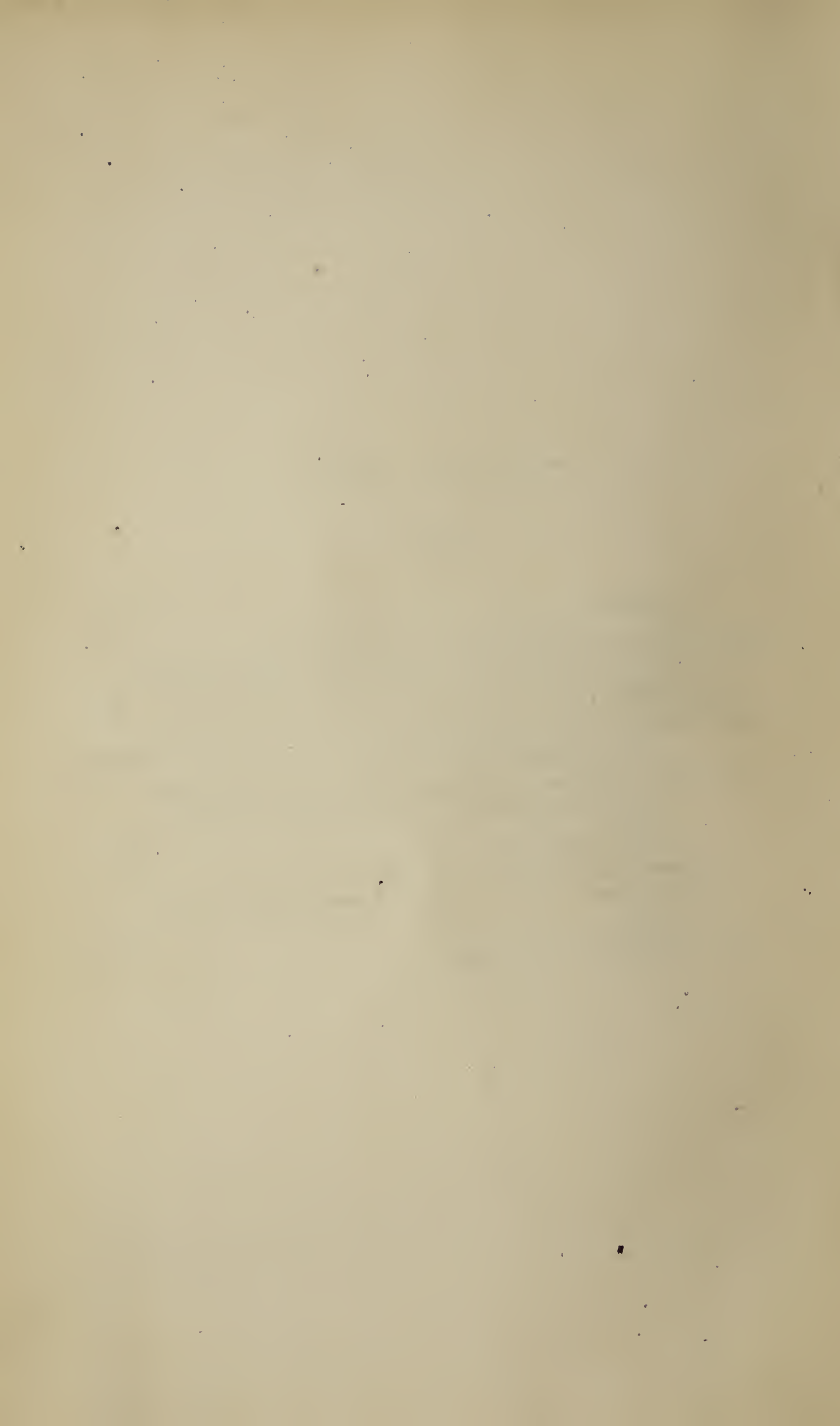
“ PAUCIS NATUS EST, QUI POPULUM ÆTATIS SUÆ COGITAT : MULTA ANNORUM  
MILLIA, MULTA POPULORUM SUPERVENIENT : AD ILLA RESPICE, ETIAMSI OMNIBUS  
TECUM VIVENTIBUS SILENTIUM . . . [ALIQUA CAUSA] INDIXERIT : VENIENT, QUI  
SINE OFFENSA, SINE GRATIA JUDICENT.—SENECA, EPIST. LXXIX.



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THE  
ECONOMY  
OF THE  
ANIMAL KINGDOM,  
CONSIDERED  
ANATOMICALLY, PHYSICALLY, AND PHILOSOPHICALLY.

PART I.

THE BLOOD, THE ARTERIES, THE VEINS, AND THE HEART,  
WITH AN INTRODUCTION TO RATIONAL  
PSYCHOLOGY.



# THE ECONOMY OF THE ANIMAL KINGDOM.

## PART I.

### INTRODUCTION.

1. THE animal kingdom, the economy of which I am about to consider anatomically, physically, and philosophically, regards the blood as its common fountain and general principle. In undertaking, therefore, to treat of this economy, the doctrine of the blood must be the first propounded, although it is the last that is capable of being brought to completion.

2. In order that all things may succeed each other in proper order, it is necessary to set out from general principles ; consequently, from the blood, in which, as a type, we discern the several parts of which we are to treat. For on the nature, constitution, determination, continuity, and quantity of the blood, depend the fortunes and condition of the animal life. The vessels, namely, the arteries and veins, are only the determinations of the blood ; and such as is the form resulting from their coalition and complication, such are the common forces and vital effects of the system, and such their particular qualifications.

3. The blood is as it were the complex of all things that exist in the world, and the storehouse and seminary of all that exist in the body. It contains salts of every kind, both fixed and volatile, and oils, spirits, and aqueous elements ; in fine,

whatever is created and produced by the three kingdoms of the world, the animal, the vegetable, and the mineral. Moreover, it imbibes the treasures that the atmosphere carries in its bosom, and to this end exposes itself to the air through the medium of the lungs.

4. Since the blood then is an epitome of the riches of the whole world and all its kingdoms, it would appear as if all things were created for the purpose of administering to the composition and continued renewal of the blood. For if all things exist for the sake of man, and with a view to afford him the conditions and means of living, then all things exist for the sake of the blood, which is the parent and nourisher of every part of the body; for nothing exists in the body that has not previously existed in the blood.

5. So true is this, that if the texture of any muscle or gland, of which almost all the viscera are composed, be divided into its minutest parts, it will be found to consist wholly of vessels containing [red] blood, and of fibres containing spirit, or purer blood. And even those parts that do not appear to consist of vessels, such as the bony, cartilaginous, and tendinous textures, will nevertheless be found, in the first softness of their infancy, to have been similarly composed. Hence the blood is not only a treasury and storehouse of all things in nature, and thereby ministers to its offspring, the body, whatever is requisite to its various necessities and uses, but it is actually all in all; and contains within itself the ground and the means by which every man is enabled to live a distinctive life, in his own body, and in the ultimate world.

6. This doctrine, however, is the last in the order of completion, presupposing, as it does, a comprehensive knowledge of those things that enter into and constitute the blood, as mentioned above (3), and furthermore, an examination of all the viscera, members, organs, and tunics, which the blood at once permeates and vivifies. If we are ignorant of the nature of these, and their mode of action, we are ignorant of the nature of the blood. The occult can give birth to nothing but the occult; in short, our knowledge of it is limited by our knowledge of those things that are known to be involved in it, and of those in which itself is known to be involved.



7. From these remarks we may readily perceive how many sciences are included in that of the blood, namely, the whole circle of anatomy, medicine, chemistry, and physics; and even of physiology; for the passions of the mind vary according to the states of the blood, and the states of the blood, according to the passions of the mind. In a word, the science of the blood includes all the sciences that treat of the substances of the world, and of the forces of nature. For this reason we find that man did not begin to exist till the kingdoms were completed; and that the world and nature concentrated themselves in him: in order that in the human microcosm the entire universe might be exhibited for contemplation, from its last end to its first.

8. In the present Part, therefore, in which I have investigated the blood, blood-vessels, and heart, and not attempted to launch out far beyond the particular experience belonging to those subjects, I could not venture to frame any other than general principles and deductions, or to propound any other than obscure notions of things. There is need both of time and of further progress, in order that what here seems obscure may be made clear and be distinctly explained. On all occasions it is desirable to take experience as our guide, and to follow the order of nature, according to which an obscure notion precedes a distinct one, and a common notion precedes a particular one. We never have a distinct perception of anything, unless we either deduce it from, or refer it to, a common fountain and universal principle. This mode of proceeding indeed accords with the original and natural condition of the senses, and of the animal and rational mind. For we are born in dense ignorance and insensibility. Our organs are opened only by degrees; the images and notions at first received are obscure, and, if I may so speak, the whole universe is represented to the eye as a single indistinct thing, a formless chaos. In the course of time, however, its various parts become comparatively distinct, and at length are presented to the tribunal of the rational mind; whence it is not till late in life that we become rational beings. In this manner, by degrees, a passage is effected to the soul, which, abiding in her intelligence, decrees that the way leading to her shall thus be opened, in order that all ac-



tions, and the reasons for all, may be referred to her as their genuine principle.

9. Being unable as yet to deliver any other than generals and universals, I foresee that many of the remarks I shall have to offer, will appear to be mere conjectures or paradoxes. They will so appear, however, to none but those who have not gone through a complete course of anatomy, physics, chemistry, and the other arts and sciences; or to those with whom preconception and prejudice forestall their judgment, and who make some one particular govern all the rest; or again, to those who have no capacity for comprehending distinctly the series and connexion of the subject. Still, as I before remarked, there is need of time and of further progress to render the subject clear; and moreover the doctrine of the blood, although it is the first we have to propound, is nevertheless the last that can be completed. The result, then, must shew, whether or not those statements, which at first perhaps appear like obscure guess-work, are in the end so abundantly attested by effects, as to prove that they are indeed the oracular responses of the truth.

10. Whether a statement be true or not, is easily ascertained. If it be true, all experience spontaneously evidences and favors it, and likewise all the rules of true philosophy: and what I have often wondered at, various hypotheses, in proportion as they are founded on some common notion, either coincide with it, or else indicate particular points of contact or approximation; much as the shadowy appearances of the morning are shewn in their connexion with real objects by the rising sun. When the truth is present everything yields a suffrage in its favor; and therefore it immediately declares itself and wins belief; or, as the saying is, displays itself naked.

11. To a knowledge of the causes of things,—in other words, to truths,—nothing but experience can guide us. For when the mind, with all the speculative force that belongs to it, is left to rove abroad without this guide, how prone is it to fall into error, nay, into errors, and errors of errors! How futile is it after this, or at any rate how precarious, to seek confirmation and support from experience! We are not to deduce experience from assumed principles, but to deduce principles themselves from experience. For in truth we are surrounded

with illusive and fallacious lights, and are the more likely to fall because our very darkness thus counterfeits the day. When we are carried away by ratiocination alone, we are somewhat like blindfolded children in their play, who, though they imagine that they are walking straight forward, yet when their eyes are unbound, plainly perceive that they have been following some roundabout path, which, if pursued, must have led them to the place the very opposite to the one intended.

12. But it may be asked whether at the present day we are in possession of such a number of facts as from these alone to be able to trace out the operations of nature, without being obliged to wander beyond experience into the regions of conjecture. In answer to this we are bound to admit, that *particular experience* or that which strictly comprehends or immediately refers to one and the same object, however rich in detail such experience may be and however enlarged by the accumulated observations of ages, can never be sufficiently ample for the exploration of nature in the sphere of causes: but if, on the other hand, in exploring each particular object, we avail ourselves of the assistance of *general experience*, that is to say, of all that is known in anatomy, medicine, chemistry, physics, and the other natural sciences, then, even at the present day, we appear to be abundantly supplied with means for the undertaking.

13. Particular experience, or that which concerns but one object, can never be so luxuriantly productive of phenomena as to exhaust and exhibit thoroughly all the hidden qualities of that object. Take for example the experiments that have been made upon the blood. These inform us merely that it is of various degrees of redness; that it is heavier than water; that it sinks to the bottom of its serum; that it is of a certain temperature; that it contains salts of both kinds [fixed and volatile], and so forth. But they do not shew us the origin of that redness, gravity, and heat; nor in what part of the blood the phlegm, the volatile-urinous, oily, and spirituous substances reside. Nevertheless these questions belong to the subject either as accidents or essentials, and can be answered and investigated only by general experience, that is, by experience in its widest meaning, or in its whole course and compass. To deter-



mine or define a thing by occult qualities is to leave it as much in the dark as before. In further illustration, we do but stop at the very threshold of the science of Angiology, unless we learn the anatomy of the body and of all the viscera, that is, diligently trace the blood through all the diversified mazes in which it flows. The same observation applies in every other instance whether of anatomy or physics. Thus in investigating the causes of muscular action, or the qualities of the motive fibre, unless we combine the particular experience of one individual with all the experience of others; and unless, in addition to this, we take into account the experience recorded concerning the blood, the arteries, the heart, the nerves, the nervous ganglia, the glands, the medulla spinalis, the medulla oblongata, the cerebellum, the cerebrum, and all the other members, organs, and tunics, endowed with the power of muscular motion: and furthermore, unless we avail ourselves of the facts that have been brought to light in physics and mechanics, respecting forces, elasticity, motion, and many other subjects,—unless we do all this, we shall assuredly be disappointed of the result for which we are striving.

14. From particular experience, as we before observed, only obscure notions are derived, but which are developed, and rendered more distinct, in the course of time and study, by general experience. There is a connection, communion and mutual relation of all things in the world and in nature, beginning from the first substance and force; one science meets and enlarges another, and each successive discovery throws new light upon the preceding. Out of a number and variety of objects, judiciously arranged and compared, an idea gathers illustration, and reason enlightenment, but still it is only in succession that its clouds are dissipated and its light emerges. Hence, in this arena of literature, if any one would attempt aught that is worthy of immortality, he must not tarry at the starting post, but measure the entire course. Now if we proceed in this manner, we shall find that at the present day we are possessed of a sufficient store of facts, and that it will not be necessary to wander beyond experience into the field of conjecture.

15. When particular experience is extended beyond its proper limits, as is frequently done, and when it is erected into an

authority for general conclusions, how often and how subtilly does it deceive the mind, which indeed lends its own reveries to the delusion! how strenuously does it seem to fight on the same side as ourselves! The ground of this is, that any fact may form a part in different series of reasonings, precisely as one syllable, word, or phrase, may be a constituent in an infinity of sentences and discourses; one idea in infinite series of thoughts; one particle or globule of an atmosphere in an infinite number of modulations; one corpuscule of salt in an infinity of flavors; and one color in an infinity of pictures. One thing may be grafted upon another as one tree upon another, and the spurious be made to thrive upon the legitimate.

16. To avoid therefore being misled by appearances, we should never give assent to propositions unless general experience sanctions them, or unless they are declared to be true by the unanimous suffrage of nature; that is to say, unless they form necessary links in the great unbroken chain of ends and means in creation. On this condition alone can an edifice be reared, which after the lapse of ages, and the testimony of thousands of additional discoveries, posterity shall acknowledge to rest upon true foundations; so that it shall no longer be necessary for each age to be erecting new structures on the ruins of the former.

17. In the experimental knowledge of anatomy our way has been pointed out by men of the greatest and most cultivated talents; such as, Eustachius, Malpighi, Ruysch, Leeuwenhoek, Harvey, Morgagni, Vieussens, Lancisi, Winslow, Ridley, Boerhaave, Wepfer, Heister, Steno, Valsalva, Duverney, Nuck, Bartholin, Bidloo, and Verheyen; whose discoveries, far from consisting of fallacious, vague and empty speculations, will for ever continue to be of practical use to posterity.

18. Assisted by the studies and elaborate writings of these illustrious men, and fortified by their authority, I have resolved to commence and complete my design: that is to say, to open some part of those things which it is generally supposed that nature has involved in obscurity. Here and there I have taken the liberty to throw in the results of my own experience; but this only sparingly, for on deeply considering the matter, I deemed it best to make use of the facts supplied by others. In-



deed there are some that seem born for experimental observation, and endowed with a sharper insight than others, as if they possessed naturally a finer acumen; such are, Eustachius, Ruysch, Leeuwenhoek, Lancisi, &c. There are others again who enjoy a natural faculty for contemplating facts already discovered, and eliciting their causes. Both are peculiar gifts and are seldom united in the same person. Besides I found when intently occupied in exploring the secrets of the human body, that as soon as I discovered anything that had not been observed before, I began (seduced probably by self-love) to grow blind to the most acute lucubrations and researches of others, and to originate the whole series of inductive arguments from my particular discovery alone; and consequently to be incapacitated to view and comprehend, as accurately as the subject required, the idea of universals in individuals, and of individuals under universals. Nay when I essayed to form principles from these discoveries, I thought I could detect in various other phenomena much to confirm their truth, although in reality they were fairly susceptible of no construction of the kind. I therefore laid aside my instruments, and restraining my desire for making observations, determined rather to rely on the researches of others than to trust to my own.

19. To find out the causes of things from the study of given phenomena certainly requires a talent of a peculiar kind. It is not every one that can confine his attention to one thing, and evolve with distinctness all that lies in it: it is not every one that can think profoundly, or as Cicero says, "that can cast up all his reasons, and state the sum of his thoughts,"<sup>x</sup> or, as in another place, "that can recall the mind from the senses, fix upon the real truth in everything, and see and combine with exactness the reasons that led to his conclusion."<sup>x</sup> This is a peculiar endowment into which the brain must be initiated from its very rudiments, and which must afterwards by a gradual process be made to acquire permanence by means of habit and cultivation. It is a common remark that poets, musicians, singers, painters, architects, and sculptors, are born such; and we know that every species of animals is born with that peculiar character which distinguishes it so completely from every other species. We see that some men come into the world as prodigies endowed



with superhuman powers of memory ; others with an extraordinary activity of the whole faculty, amounting to a peculiar strength of imagination and intuitive perception ; by virtue of which no sooner do they set the animal mind in motion on any subject, than they excite the rationality of the corresponding rational mind, they arrange their philosophical topics into a suitable form, and afterwards engage in thought till they see clearly whether their opinions are consonant with the decisions of a sound judgment ; when, if any element of an obscure character embarrasses the subject, by a happy gift of nature they separate the obscure from the clear, and in its place insert some other element more conformable to the general idea, so as to make all the parts aptly cohere. With a natural facility they distribute their thoughts into classes, and separate mixed topics into appropriate divisions ; and skilfully subordinate series, thus perspicuously divided, one under the other, that is, the particular under the general, and the general under the universal. Thus are they never overwhelmed by the multiplicity of things, but continually enlightened more and more, and, by the help of arrangement and general notions, recall to mind, whenever they please, such parts of the subject as had become effaced from their notice, and unfold such as are complicated or perplexed.

Those who are born with this felicity of talent, and afterward proceed in due order to its development, the more profoundly they penetrate into the depths of science, the less do they trust to their imagination, and the more cautious are they not to extend their reasoning beyond the strict limit justified by facts : or if they indulge in conjecture at all, they treat it as mere surmise and hypothesis until experience bespeaks its correctness. They avoid as a hydra any premature attachment to, or implicit credence in, opinions, unless there are circumstances duly to support them. Even if they retain them in their memory, they do not admit them as links in any chain of reasoning ; but while conducting their argument, in a manner banish them from thought, and keep the attention fixed on data and facts alone. The fictitious depresses them, the obscure pains them ; but they are exhilarated by the truth, and in the presence of everything that is clear, they too are clear and serene. When,

after a long course of reasoning, they make a discovery of the truth, straightway there is a certain cheering light, and joyful confirmatory brightness, that plays around the sphere of their mind; and a kind of mysterious radiation,—I know not whence it proceeds,—that darts through some sacred temple in the brain. Thus a sort of rational instinct displays itself, and in a manner gives notice that the soul is called into a state of more inward communion, and has returned at that moment into the golden age of its intellectual perfections. The mind that has known this pleasure, (for no desire attaches to the unknown,) is carried away wholly in pursuit of it; and in the kindling flame of its love despises in comparison, as external pastimes, all merely corporeal pleasures; and although it recognizes them as means for exciting the animal mind and the purer blood, it on no account follows them as ends. Persons of this cast consider the arts and sciences only as aids to wisdom, and learn them as helps to its attainment, not that they may be reputed wise for possessing them. They modestly restrain all tendency to inflated ideas of themselves, knowing that the sciences are an ocean, of which they can catch but a few drops. They look on no one with a scornful brow, or a supercilious air, nor arrogate any praise to themselves. They ascribe all to the Deity, and regard Him as the source from whom all true wisdom descends. In the promotion of his glory they place the end and object of their own.

20. But those who go in opposition to nature, and with no wisdom to befriend them, and strive to intrude themselves arbitrarily into this condition, are only doing violence to their powers. The more they attempt a transition from one reason to another, and to draw a single conclusion from all, the more do they entangle the threads of their argument, till they enclose themselves within the folds of the intricate web they have woven; and at last are enshrouded in darkness, from which they find it impossible by their own endeavors to escape.

These chiefly are they whom the sciences and a multiplicity of studies benight and blind, or whom learning infatuates. These are they who invent senseless hypotheses, and gravely invite the public to visit their castles in the air. Who display an absurd ambition to narrow the limits of knowledge, and persuade



themselves that there is no cultivated land beyond the borders of their own muddy lake. Who, if haply their eyes be opened, nevertheless contend to the last for the false against the true. Who proclaim that nature is altogether beyond the reach of human comprehension, and consign her to chains; bidding the world despair of seeing her liberated at all, or at least for ages. Who claim all wisdom as an attribute of memory, and hold nothing in esteem but bare catalogues of facts, regarding as of no account any enquiry into their causes. Who, in imitating the character of others, and omitting their own, or in fighting fiercely under another's standard, fancy themselves among the leading geniuses of the age, and think they have merited the leadership. Who consider themselves as having revealed the secrets of Delphos, if they have only been able to invest the obscure oracles of another mind with some new, and as they suppose ornamental, costume of their own. All which errors of theirs arise from the fact, that they have not learnt to measure their genius by the rule of nature.

21. As the natural gift we have mentioned, or the faculty by which the understanding sees acutely and distinctly into the series of things, is to be perfected by the use of means; so even where this faculty is by nature excellent, there are many things that retard its advancement, diminish its energy, and enfeeble its efforts. Such, for instance, are the desires of the animal mind and the pleasures of the body, which render the rational mind, when too compliant to them, unable any longer to pursue its high investigations; for then it is as it were in bonds, and forced to go wherever lust will have it. This faculty is impaired and destroyed also by the cares and anxieties arising from domestic circumstances and the consideration of worldly prospects. For these determine the mind to low and outward things, and never raise it to the high and the inward. Nothing superinduces more darkness on the human mind, than the interference of its own fancied providence in matters that properly belong to the Divine Providence.

22. This faculty, however, is chiefly impaired by the thirst for glory and the love of self. I know not what darkness overspreads the rational faculties when the mind begins to swell with pride; or when our intuition of objects calls up in the ob-

jects themselves the image and glory of our own selfhood. It is like pouring a liquor upon some exquisite wine, which throws it into a froth, sullies its purity, and clouds its translucence. It is as if the animal spirits were stirred into waves, and a tempest drove the grosser blood into insurgent motion, by which the organs of internal sensation or perception becoming swollen, the powers of thought are dulled, and the whole scene of action in their theatre changed. In those who experience these disorderly states, the rational faculty is crippled, and brought to a stand-still; or rather its movements become retrograde instead of progressive. A limit is put to its operations, which its possessor imagines to be the limit of all human capacity, because he himself is unable to overstep it. He sees little or nothing in the most studied researches of others, but everything, oh! how vain-glorious, in his own. Nor can he return to correct conceptions, until his elated thoughts have subsided to their proper level. "There are many," says Seneca, "who might have attained to wisdom, had they not fancied they had attained it already."<sup>x</sup> The Muses love a tranquil mind, and there is nothing but humility, a contempt of self and a simple love of truth, that can prevent or remedy the evils we have described.

But how often does a man labor in vain to divest himself of his own nature. How often, when ignorant or unmindful of the love that creeps upon him, will he betray a partiality to himself and the offspring of his own genius. If an author therefore desires that his studies should give birth to anything of sterling value, let him be advised, when he has committed to paper what he considers to be of particular merit and is fond of frequently perusing, to lay it aside for awhile, and after the lapse of months to return to it as to a something he had forgotten, and as the production not of himself but of some other writer. Let him repeat this practice three or four times in the year. In accordance with the advice of Horace,—

"Reprehendite, quod non  
Multa dies et multa litura coercuit, atque  
Perfectum decies non castigavit ad unguem."

*De Arte Poeticâ*, l. 292—294.

Should his writings then often raise a blush upon his countenance, should he no longer feel an overweening confidence with



regard to the lines which had received the latest polish from his hands, let him be assured that he has made some little progress in wisdom.

23. I think that I shall not at all detract from the literature of the present day, if I aver with many, that the ancients surpassed us in wisdom, in the art and perfection of distinguishing things, and in the shrewdness of their conjectures respecting the occult. For with no instruction save their own, they laid the foundations of numerous arts and sciences upon which their posterity afterwards built; nay, from the resources of their own genius and without being under any intellectual obligations to the past, they raised the superstructure to no inconsiderable height. Of the truth of this fact, we have evidence in their writings, which, more lasting than brass, have been handed down uninjured through an interval of thousands of years even to this very day. The instructive lessons they have taught, and the opinions they have pronounced, we, their posterity and children, are still wont to respect, to receive, and to apply to the practical purposes of life. It is scarcely necessary to mention such names as Aristotle, Hippocrates, Galen, Archimedes, Euclid, and others.

24. On the other hand, I think I shall not detract from the praise due to ancient literature, if again with many I aver, that the late and present ages are distinguished above those of the ancients for the aids they have afforded in carrying to a farther extent the developments of genius, or for accumulating experimental facts; thus for supplying posterity, of whom we have the brightest hopes, with materials for a wisdom that is yet to come. Each therefore has occupied its peculiar province; the ancients excelling in genius; the moderns abounding in materials that may afford support to future genius.

25. Thus does it seem to be the will of that Providence who rules all earthly affairs, that the one state should be succeeded by the other; that the parents should instruct the children; and that the ancients should incite their posterity to the acquisition of the experimental knowledge by which their contemplative sciences may be confirmed: and in like manner that we of the present age should stimulate the generations that follow us, to work again and again in the mines of the same experi-



ence, so that they, in their turn, may attain to a deeper insight, and a further progress: in fine, that various ages should cultivate various kinds of learning; in order, as it would appear, that the sciences may at last arrive at their destined perfection.

Whether we contemplate the sphere of generals or particulars, we always behold nature busied in alternations. She pours around the world the light of day, and then the darkness of night, and from darkness leads on a new day through the gates of the breaking dawn. She advances from spring to summer, and from summer to autumn, and returns through winter to spring-time. She guides the infant through youth and manhood to old age, while at the same time she is preparing a new generation to enter on the years of infancy and youth. By like alternations, or a similar order of things, it is reasonable to suppose that the republic of letters is governed. First came the day, and the world was enlightened with the brilliance of genius; then the night, and for ages the human mind lay slumbering in darkness. Now again the dawn is near, and we abound in experience. Haply the progress hence will be to a new day and a second age of genius.

26. And the time is at hand when we may quit the harbor and sail for the open sea. The materials are ready: shall we not build the edifice? The harvest is waiting: shall we not put in the sickle? The produce of the garden is ripe and ripe: shall we fail to collect it for use? Let us enjoy the provided banquet, that is to say, from the experience with which we are enriched, let us elicit wisdom. Had such a store as we possess been set before the sages of antiquity, there is reason to presume, that they would have advanced the sciences to the heights not only of Pindus but of Helicon. Nor will there be wanting men at this day, with this splendid inheritance of knowledge; who,—provided they devote their minds to the object from their earliest years, and with their full native powers, and do not suffer themselves to be carried away by the sensual pleasures and dissipations of the age,—will carry the same sciences beyond the Pindus of the ancients.

27. But to launch out into this field is like embarking on a shoreless ocean that environs the world. It is easy to quit the land, or to loose the horses from the starting-post, but to attain

the end or reach the goal is a labor for Hercules. Nevertheless we are bound to attempt the abyss, though as yet we must proceed like young birds, that with the feeble strokes of their new fledged wings first essay their strength, and from their nests try the air, the new world into which they are to enter.

28. But all this contributes nothing to the business before us, or to the knowledge of the blood. I shall therefore detain the reader no longer, but proceed immediately to the matter in hand. Allow me to observe that in each chapter of the ensuing treatise I have prescribed to myself the following method. First, by way of introduction I have premised the experience of the best authorities, adhering closely to their own words, that nothing may be suppressed which may be suspected of militating against my views. Next I have proceeded to form some general inferences, and to confirm them one by one by the previous experience, so far as it has gone, the latter serving as the foundation of the present work ; my principal object in which, is, to let fact itself speak, or to let causes flow spontaneously from its lips.





## CHAPTER I.

### THE COMPOSITION AND GENUINE ESSENCE OF THE BLOOD.

29. LEEUWENHOEK has observed, that blood drawn from his own hand was composed of red globules floating in a crystalline humor not unlike water, but that he was in doubt whether all blood was of the same nature. He says, that upon a close examination of the globules, after separating one from the other, and even dividing some of them, they presented the appearance of being very slightly colored. Milk he found in like manner to consist of globules floating in a limpid humor, but these were transparent. (*Philosophical Transactions*, n. 102, p. 23.) He also clearly discerned, as he says, that every globule was compounded of six smaller ones, which were as flexible and soft as the larger. That in proportion as the larger were stretched out or elongated, the smaller assumed the same lengthened figure, till they became like threads. He also relates that he had subjected the larger globules to violent motion, when they burst in pieces, and displayed the smaller globules. Also that the globules of milk were of different dimensions, but that those of the blood were of only one dimension. (*Lectiones Cutlerianæ*, v., p. 84—86.) He saw that the globules were flexible and pliant in proportion as the blood was healthy, and in passing through the small capillary arteries and veins, changed to an oblong figure, (*Phil. Trans.*, n. 117, p. 380,) three times as long as broad : also that they passed by and into one another, and by reason of their softness could be moulded into various shapes, but when at liberty immediately recovered their former globular condition. Where many globules came together, and lost their heat, they appeared as a uniform matter in which no parts were distinguishable. (*Lect. Cutl.*, p. cit.) When the author was ill, the globules of the blood he drew from himself appeared to be harder and firmer ; but when he was in a good state of health, they were better connected with each other, being softer and

more fluid : whence he infers, that death may sometimes proceed from the hardness of these globules. (*Phil. Trans.*, n. 117, p. 380, 381.) When he examined blood possessing much crystalline liquor, and placed in one of his tubes, and carried it into the open air at a time when there was a pretty strong wind, he observed that the globules were agitated, like the air itself, by concussions and mutual motions ; and he observed moreover another kind of motion, in that each globule gyrated round its own axis. (*Ibid.*, n. 106, p. 129, 130.) He likewise observed that the transparent liquor in which the red globules of the blood swim, itself consisted of small globules, which were fewer before evaporation than after. In the same liquor he also distinguished certain bodies of a quadrangular figure, which he considered to be saline particles. (*Ibid.*, n. 117, p. 380.) But the globules of the blood, he says, are specifically heavier than the crystalline liquor, for the moment they escape from the veins, they by little and little subside toward the bottom ; and being made up of soft, fluid corpuseules, and lying one upon another, they unite together, and by their close conjunction, the blood that is under the surface alters its color, and becomes dark red, or blackish. The red globules, he says, are 25,000 times smaller than a grain of sand. (*Ibid.*, n. 106, p. 122.) He observed that in a tadpole the particles of blood were flat and oval, and that sometimes, by reason of the tenuity of an artery, they were made to assume a tapering figure, and were so minute, that a hundred thousand myriad of them could not equal in bulk a large grain of sand. (*Epist.* 65, *Arcana Naturæ Detecta*, p. 161, 162.)

30. LANCISI. "Microscopical experiments demonstrate, that the blood consists principally of two parts, namely, of serum which is mostly limpid in healthy subjects, and of extremely minute globules from which the general mass of this fluid derives its redness, whether it be in circulation, or intercepted in any part of the system. . . . Leeuwenhoek observes, that in fishes he found that the particles which occasioned the redness of the blood were plano-oval ; that in land animals they were round, so far as he could judge from the eases that came under his own inspection. But that in human blood these globules were soft, and each of them formed by the union and conjunction of six smaller globules. To these he attributes the redness of the blood, and considers that it is deeper and more intense the more numerous they are, and the more agglutinated the one to the other. With respect to my own observations I would remark, that I have made them with the greatest care, and with the assistance also of the illustrious Blanchinus. There are four principal things that we noticed in drops of blood recently drawn, when received on a crystal plate and submitted



to the microscope. 1. Innumerable globules of a red color, which on examination appeared to be mixed up with a transparent serum, and swimming in it, but which, when the serum had soon after partly evaporated and partly concreted into reticular fibres, became perfectly fixed and immoveable. 2. The globules were not of an oval figure, nor composed of others, much less of the number six, but each was almost spherical and was perfectly distinct in itself. 3. So long as the serum remained in a state of fluidity, if the crystal plate on which the particle of blood had been dropped was turned in one direction or the other, the globules followed with such rapidity, as evidently to shew that they were heavier than the serous fluid. 4. In the part where the blood had been converted into clot, and had almost become black, the globules were more crowded, and lying one upon another. In those parts where the blood was more diluted, or less red, the globules were fewer, and farther apart from each other; so that we could not doubt that the degree of redness in the color of the blood depended upon the relative closeness in which the globules were held in connection by the serum. In the case of blood extracted from the veins, and received into a vessel, we observed that the part which occupied the bottom became black, and that the part at the top and in contact with the external air became red and brilliant; and the question arose among us, whether this was the consequence of a larger abundance of those globules which, as their specific gravity is greater than that of serum, subside and accumulate at the bottom, and are hence less diluted by the serum than those which occupy the upper part. For this reason it is, that if coagulated blood be inverted, the part that has previously been black soon changes to a purple color. . . . For a similar reason arterial blood is redder than venous. . . .

“Since the blood is composed of those elementary principles by which we are nourished, and since all our food, whether solid or liquid, contains among other particles such as are round and globular, (as we have discovered by microscopical observation in all farinaceous aliments, fruits, milk, wines, beer, and other things of the same kind), hence the blood which arises out of the same aliments, solid or liquid, is on this account itself for the most part composed of very minute globules. . . .

“I must not omit to mention a fact which the celebrated Malpighi pointed out to me at Rome, and which the learned Gulielminus, who himself received it from Malpighi, subsequently confirmed, namely, that if the serum of any kind of blood be dried in the shade upon a piece of clean crystal or talc, it deposits spiculæ of various salts, both simple and compound; among the simple, for instance, spiculæ of vitriolic, aluminous, nitrous, and sea salts; among the compound, spiculæ

of salts of tartar, and several kinds of volatile salts. Considering this to be a fact established by experiment, we proceeded to examine through the microscope different small drops of particular fluids, as tears, the mucus of the nares, sweat, urine, saliva, and so forth; all of which presented to us spectacles of singular beauty on account of the variety of forms that they exhibited. . . . In these cases we discerned a likeness to various objects, here, to the figure of a cross, there, to a tree, or a branch, in another instance, to a comb, but the most common resemblance that they bore was to a fern. (*De Motu Cordis*, &c., postulat. xvi.)

“The proportion of aqueous and other fluids to the saline, earthy, and various solid bodies constituting the blood, appears to be, according to the Hon. Robert Boyle, a little less than that of 4 to 1. For of 10 ounces and 73 grains, or 5,833 grains, of recent venous blood, he observed that after distillation there remained of the thick dried portion two ounces and two drachms, or 1,296 grains; 4,223 grains having been converted into phlegm, and 214 grains having evaporated sensibly, and been dissipated: whence it must be inferred, that the fluid portion amounted to 4,537 grains. Now since the dry residuum, or caput mortuum, amounted as we have said to 1,296 grains, hence the fluid part is to the solid in the proportion of a little less than 4 to 1, or nearly of  $3\frac{1}{2}$  to 1. It is not impossible however that by the action of the fire some even of the solid particles as well as of the fluid were carried off from the blood, as we see in the case of soot, which is nothing more than a congeries of sulphureo-solid particles, forced away by the fire and carried up with the smoke. Hence if the solid parts thus carried off be added to those that remain in the caput mortuum it follows, that the proportion of the solid to the fluid part of the blood is a little more than that of 1 to  $3\frac{1}{2}$ , which, without occasioning any material error, we may suppose to be the same with the proportion of 1 to 3, adverted to with his accustomed care by our friend Gulielminus. Here however we wish to remind the reader, that this proportion is not found to be the same in all subjects, nor in the same subject at different times, but must vary according to the temperament, age, climate, and season, and more especially according to the different quantities of food necessary for different individuals, and to the different intervals occurring between the extraction of the blood and the ingestion of the solid or liquid aliment. . . . This subject however we have treated of more at large in another place, in which we have shewn that there can be no certain and determinate proportion either of the parts of the blood one to the other, or of any part or parts to the whole. It is however manifest, that by the action of the fire



almost the same principles may be separated from the crassamentum as from the serum; namely, 1. Urinous phlegm. 2. Volatile salt, of which with a small proportion of phlegm a spirit is composed. 3. A yellow and a black oil. 4. An ash or earth in combination with saline particles, from which by boiling may be separated a fifth principle, namely, a fixed salt approximating very nearly to the nature of sea salt. The proportion however of these elementary principles in the serum is different from what it is in the crassamentum, since in the serum the aqueous part, and the part consisting of volatile salts, is more abundant, but the earthy, the fixed saline, and the oily parts, more scanty. On the other hand, in the crassamentum, there is less of the liquid part and more of the other parts. Of the oils which, as we have said, are extracted by the action of fire principally from the crassamentum itself, the yellow is of less specific gravity than the black, because the black contains sulphureous-earthly particles in a much greater quantity than the yellow. Hence many persons form no unreasonable conjecture, that the black is elicited more particularly from the globules of blood which are most abundant in the crassamentum. (*Ibid.*, postulat. xvii.)

“Although there are some even at the present day who will deny that any air travels through the vessels and is mixed up with the blood, yet that air actually exists in the blood is most clearly proved by the air-pump when carefully adjusted; for if blood be placed under the receiver, not only has Boyle, but we ourselves have often observed it emit bubbles, and almost effervesce, the moment the internal air is liberated from the pressure of the atmosphere. Nor does what Leeuwenhoek asserts, namely, that no air can be obtained from fresh venous blood, but only from that which has for some hours been exposed to the atmosphere, at all shake me in my opinion, for the circumstance he states is the consequence only of an imperfect adjustment or construction of the machine, . . . since not only have I been eye-witness to the escape of air from fresh venous blood, occasioned by the action of a powerful air-pump, but I have also actually observed the existence of air in the blood contained within the veins of a hedgehog.” (*Ibid.*, postulat. xv.)

31. BOERHAAVE. “The cruor or blood in the veins of a dead body continues for a long time mixed and fluid, without any coagulation, but that in the heart and arteries soon coagulates. . . . During life the blood appears to be of a uniform redness, but when viewed through the microscope it is found to consist of red spherules swimming in a thin and almost transparent serum. These spherules or globules derive their color from being composed of six smaller ones; and when divided into their component parts, present the appearance of

a pellucid yellowish serum of various shades. . . . It is difficult to ascertain how far the division into lesser globules proceeds. . . . The red blood is the grossest of all the humors that a state of health nurtures and cherishes in the viscera, arteries, and veins. The next of the humors in the order of grossness or fineness [in regard to its particles], is the yellowish serum which is coagulable by heat. The next is the colorless juice, which is similarly coagulable; then the limpid humors which do not coagulate by heat, with the lacteal, urinous, and all other fluids gradually decreasing in the size of their particles, but not yet accurately classed or enumerated." (*Inst. Med.*, n. 225, 226.)

32. DOMINICUS GULIELMINUS. "No one denies that a vast number of globules or molecules exist in the blood as compound bodies [undergoing no resolution]. Particles of bile are clearly observable in blood drawn from a vein, and in jaundice, when there is an accumulation of these particles, they tinge the whole skin. . . . The same thing has been noticed by Lower respecting the chyle, by Malpighi respecting the sanguineous fibre, and by Leeuwenhoek respecting the plano-oval corpuscles [of the blood] . . . . Water is most clearly discernible in the blood, as well as saline spiculæ. . . . (*De Sanguinis Naturâ et Constitutione*, n. 29.) The blood of fishes is cold to the touch; in what are called bloodless animals, it is colorless or yellowish. (*Ibid.*, n. 30.) When particles of air are brought into contact with the sanguineous mass, they impart to it a red and rosy color. (*Ibid.*, n. 34.) Those who have noticed extravasated blood, have not perceived in it anything analogous to air. . . . Nevertheless, when in contact with air, blood, whether arterial or venous, changes its color, and the upper part of venous blood, although previously dark, if exposed to the air, in a short time assumes the arterial hue. . . . Nitre, if poured on blood, imparts to it the same color as air. . . . We may therefore conclude with probability, that the particles which the air supplies to the blood, are of a nitrous character, but highly volatile. (*Ibid.*, n. 35.) It is observed by Lower, that useless particles, which have been previously repudiated by nature, and heterogeneous miasmata, are sometimes absorbed into the blood-vessels, by the arterial extremities, or by the fleshy substance, or rather by its porosities and interstices. (*Ibid.*, n. 41.) If blood be placed in an air-pump, and the receiver be exhausted, it emits an abundance of particles of air, just as water does. (*Ibid.*, n. 42.) When blood has been recently drawn from a vein, we find warm halitus issuing from it in the form of steam or vapor, and perceptible both to the sight and touch. . . . Arterial blood is warmer, redder, brighter, and thinner than venous blood. (*Ibid.*, n. 43.) In proportion as its warmth subsides, . . . the blood coagulates into a mass of



coliering particles, which is denominated red crassamentum, the other part turns into a watery fluid which is called serum. The crassamentum is heavier than the serum, for the former sinks to the bottom, and leaves the latter supernatant. . . . The parts of the crassamentum are at first united to each other in such a manner, that sometimes the whole blood appears to be but one concrete mass, without any appearance of serum. . . . If blood so coagulated be well shaken, or cut into pieces, the serum immediately presents itself, . . . and rises to the top. Hence it happens, . . . that a portion of serum, sometimes greater, sometimes less, is expressed by the crassamentum, . . . and if it be not so expressed, the cruor assumes the appearance of ink, and becomes almost homogeneous and not coagulated, but thick and muddy. (*Ibid.*, n. 44.)

“The concrete portion when viewed by the microscope appears to be compounded of two parts, one whitish or yellowish, originating from fibres mutually interwoven, and which is therefore defined as the fibre of the blood; the other red, and formed wholly of minute globules. Hence if the concrete portion be repeatedly washed in warm water, the red color leaves it, together with the before-mentioned globules, and passes into the water (*Ibid.*, n. 46). The red globules are formed of other globules, as Leeuwenhoek observes, and these of certain pellucid bodies, which by reason of their peculiar figure have obtained the name of plano-oval particles. These are the only particles which are colorless, or quite transparent. If, however, a number of them be placed one upon another, they exhibit a reddish tinge. (*Ibid.*, n. 47.) It frequently happens, . . . that the portion of blood which lies at the bottom of any mass, is not only of a darker color, but also of a looser compages. . . . If the clot be inverted, and the lower part be exposed to the air for three quarters of an hour, it is not only deprived of its foul color but is imbued with a rosy tint. (*Ibid.*, n. 48.) It sometimes happens that the upper part of the clot has no appearance of redness, but turns into a yellowish gelatinous substance, while the lower part is of the foulest hue. . . . I remember having myself observed the red globules descending in heaps to the bottom, and at the same time a gelatinous crust forming at the top and absorbing all the serum; none of which made its appearance either then or afterwards. . . . The thicker, whiter and denser the gelatinous crust of the crassamentum, the more flaccid and black is the other part of it. (*Ibid.*, n. 49.) With regard to the presence of fibre, Malpighi and Bohn are at variance. The former asserts it; but the latter denies the fact, because on a very close examination of fluid and warm blood he found in it no appearance of fibril or filament. . . . We take it as certain, . . . that the crassa-



mentum of blood consists of reticulated fibres, between which are loculi, porosities, areolæ, or interstices, in which both the serum of the blood and its red globules are contained. . . . If we make our observations upon coagulated blood, all this will be plain, but it will be not less so if we carefully examine the blood by the microscope during the process of coagulation. For although while the blood is in a fluid state, there is no appearance of filamentary composition. . . . yet as soon as the blood manifests any tendency to concretion, and the warm particles evaporate, certain fibrils or stamina begin to display themselves, and which are at first only small, but by agglomeration produce larger ones, that in course of time adhere to each other, and becoming mutually implicated or interwoven, form a reticular mass, . . . and are disposed longitudinally into stamina. (*Ibid.*, n. 50.) The serum of the blood is either limpid, almost like water, or it is turbid, and not seldom milky, or red, or yellowish, or greenish. When limpid, it is in a natural state; . . . it becomes turbid when opaque particles are associated with it; . . . it becomes milky from the admixture of unresolved chyle; it is red, if it retains any of the red globules, . . . and yellowish or greenish, if it possesses any molecules of bile. (*Ibid.*, n. 51.) If a piece of glass be wetted in serum, and suffered to dry, we find that the serum, whatever be its quality, deposits on the surface the spiculæ of different salts, some simple, others compound. . . . More than once I have observed, as first shewn by the illustrious Malpighi, both vitriolic, aluminous, tartareous, nitrous, and salso-muriatic spiculæ, and this, with the microscope alone, apart from all chemical preparation. . . . The serum of the blood when submitted to the action of fire, leaves, after almost complete evaporation, a gelatinous substance, which by continuing the heat is condensed as it were into osseous, pellucid, horny lamellæ. This part has been called by medical writers the serum concrescibile, and is the same with that which forms the white crassamentum. (*Ibid.*, n. 52.) If the steam of serum escaping into the atmosphere during the beforementioned process of evaporation, be received into an alembic, a liquor is collected which both in smell and taste resembles urine; nay, which is no other than urine itself, according to the experiments of Boyle, so far as they go. Thus, firstly, we find that both serum and urine extract from copper a blue tincture that forms no bad remedy in cases of lacrymation and ophthalmia, and other similar diseases of the eyes. Secondly, in the congelation of both these liquors we observe little glacial laminæ of a pectinated figure. Thirdly, both serum and urine serve to form an invisible ink, the characters of which are brought out by heat. When we add to these proofs, that there is an agreement between the two in

point of taste and smell, it would appear as if we had a right to assert, that the urine is nothing but the serum of the blood freed from its red globules and fibrous portion. (*Ibid.*, n. 53.) It is well known from the experiment made by Bellini, that urine contains water, an insipid earthy matter, or tartar, and salts of several kinds, both fixed and volatile, and in addition to these, some portion of sulphur. . . . Boyle has shewn that by distillation, . . . little grains of salts both fixed and volatile may be extracted from the serum of the blood, as also an active volatile spirit, . . . besides which not a few little drops of a most fetid oil come over, which correspond to the sulphur discoverable in urine ; and finally a caput mortuum, although in extremely small quantity, is left behind. (*Ibid.*, n. 54.) The crassamentum yields [on distillation] an abundance of insipid phlegm and salts of both kinds, whereof the volatile, combined with a small portion of water, constitute a spirit ; but the fixed, mingled with the caput mortuum, are brought out at last by continued calcination and boiling. Two kinds of oils moreover are obtained ; one, intensely red, verging to blackness ; the other, somewhat of a pale amber color ; one floats on the top of the other, and if they are mixed together, they soon separate and return to their former relative situation. . . . There is this one difference between the serum and the crassamentum, in regard to their chemical principles, that the serum has by far the greater quantity of water, the greater number of salts, and these in a free or volatile state, a small portion of fixed sulphur, but scarcely a trace of volatile sulphur, and almost no earth. But the red crassamentum, as it has a greater quantity of oil, so has it also a very large share of a more fixed sulphur, a less proportion of phlegm, more of earthy matter, and yet not much. Salt is about equally abundant in both, and in the crassamentum it is usually fixed, . . . although both volatile salt and spirit can be extracted from it. (*Ibid.*, n. 55.) There is greater difficulty respecting the fat, which some anatomists suppose to be separated from the blood, and others to be derived from the stomach and primæ viæ, and affused upon the blood. . . . Certain it is, that not a trace of oil or fatty substance appears in the blood. . . . I am of opinion that fatty matter exists in the blood either in a state of resolution, or not as yet combined into that peculiar form that it assumes when contained in its proper sacculi and striæ. (*Ibid.*, n. 55<sup>2</sup>.) Leeuwenhoek says . . . that the plano-oval particles are not only separated from each other in the capillary vessels, but are even comminuted into others which are smaller and colorless. (*Ibid.*, n. 62.) If the powder of dried crassamentum be thrown into the flame of a candle, it instantly catches fire like resin, and explodes with a noise and crackling, which is the effect of salts ;



giving rise to the inference that sulphur is present in the watery portion of the blood, and this in a very subtile and volatile form. (*Ibid.*, n. 67.) The blood of young persons is hotter than that of the old, for which reason also their actions are more vigorous. The blood of old persons is more vapid, and hence their debility, their tendency to disease, and the difficulty they experience in regaining health." (*Ibid.*, n. 83.)

33. MALPIGHI. "If you desire a beautiful spectacle, examine through a microscope the fibrous contexture of a portion of clotted blood that has been well washed, and you will see a network of as it were nervous fibres, the little cell-like interstices and cavities of which are occupied by a red ichor, that when wiped away leaves the reticular structure whitish, so as to present to the naked eye the appearance of a mucous membrane. A diligent examination of the sanguineous crust will probably shew that this reticular portion of the blood is formed of the same material, and is of the same nature, as the crust that floats upon [the blood]. For if we take coagulated blood, with a large and thick white crust, that is not distended with concretable serum, but forms a kind of coat, soft and pliant, and cut it into longitudinal slices, and then repeatedly wash it, we shall observe on its upper part a crust of pellicle composed of whitish channels and almost pervious with vesicles, which are filled with a transparent juice of a less specific gravity than itself; and if we trace the production of this substance still farther, just where the coagulated mass of blood begins to redden, we shall find it elongated downwards, and divided into a fringe-work of little fibres, creating by their beautiful implications little winding channels and sinuses, which are distended and tinted by the red atoms they enclose; and we shall moreover observe a yellowish serum confined in some of the larger spaces, or confounded with the red ichor. . . . There is one thing of which I would remind the reader, namely, that the concretable serum detained in the interstices of the crust, as well as throughout the whole mass of the fibrous texture of the blood, becomes inspissated in certain disorders, and that this gives rise to a pale and cinereous color, and to the same mucous character, and the same kind of substance as are observable in concreted serum and albumen. There are also not unfrequently certain elongated appendices developed through the entire mass of the blood, to which on every side hang meshes of lesser offsets which are sometimes visible without the microscope. . . . Polypi grow and enlarge generally in the right more easily than in the left ventricle of the heart, and readily also in the different venous channels of the lungs and the head, where they are produced not unfrequently. . . . There is reason to believe that nature, in her solicitude to maintain the fluidity of the blood, is constantly pouring on it



and mingling with it a certain fine and highly-active principle, by the motion and figure of which the mixture of the parts of the blood is facilitated, as well as their disposition to resolve and circulate. . . . This salt of life is eliminated by the lungs by means of fermentation, either from the liquids brought by the blood, and particularly from the lymph; or as I incline to think, from the external air, since the lungs themselves are analogous to glands in structure. For it is probable that they sift into the blood while passing through them, certain corpuscles that the ancients considered to be portions of brute souls, and hence give rise in the plexuses of the pulmonary vessels to the red portion of the blood, by facilitating the attenuation, agitation, and mixture of the juices conveyed to them. For in cruor, where this polypous crust abounds, only a slight degree of redness is observable; and, again, where this redness abounds the polypous crust does not. This view is countenanced by the frequent occurrence of pleuritis during atmospheric changes. . . . I know that authorities of the greatest weight have thought that at such times a larger quantity of nitre is collected and mixed with the blood, by which it is fixed and coagulated: but I doubt the fact; for six ounces of nitre in solution introduced into the jugular vein of a dog of middling size and strength, produced no sensible change, except an abundant secretion of urine; in other respects the animal continued in perfect health. It is, therefore, probable that no coagulation of the blood had ensued, such as we find after the injection of certain kinds of aqua regia. . . . Oil of sulphur poured upon the blood makes those parts swell that it is in immediate contact with and on which it floats, converting them ultimately into a baked and black substance, forming a solid crust. The same result is produced by oil of vitriol. Powdered alum sprinkled on the upper and still fluid part of a quantity of blood, turns it black, and gives the cruor itself a burnt appearance. When powdered nitre, or nitre dissolved in water per deliquium, is placed upon blood, it produces upon the surface a thin substance of a deep purple color, and the same thing occurs when aqua vitæ, common salt, rock salt, sal ammoniac, sulphur and hartshorn are made use of in the same way. Nearly all these substances appear to retard the coagulation of the blood for a short time.” (*De Polypo Cordis Dissertatio*).

34. VERHEYEN. “If blood recently drawn in a vessel be well stirred with a wisp, it not only acquires and for a long time retains a redder color, . . . but also remains fluid for a considerable period. Neither does it easily separate into two parts, like blood that is kept quiet from the time of its being drawn. . . . However fluid blood may be, it is thickened by the slightest warming, and even by the applica-

tion of a greater degree of heat, and acquires a dark color, like boiled liver, even though it be continually stirred. . . . The more serous portion which, if suffered to remain at rest, separates in the basin from the crassamentum, likewise thickens upon the application of heat, and acquires the consistence and almost the color of the white of an egg moderately boiled; a little serum impregnated with salt separating from it. . . . Blood coagulates on the addition of acid, even in the living body, as I have ascertained by injection, and acquires various colors according to the particular acids injected. Spirits of nitre cause it to assume an obscure white. Spirits of vitriol turn it black, as does also vinegar, but less intensely. Spirits of salt turn it to a color intermediate between the two produced by spirits of vitriol and spirits of nitre; namely, to a dark ashy color, having an unpleasant appearance. Salts of Saturn also thicken the blood and turn it pale, though not to such a degree but that the red color is still predominant. Vitriol gives the blood an ashy, obscure, dirty color, but artificial vitriol, commonly called salt of steel, changes it in a much less degree. Sea salt and nitre give the blood a duskier and redder color, and in some measure hinder its coagulation. Alkaline salts produce the same result, but more effectually. Blood that has been blackened by the addition of spirits of vitriol, I have exposed to the air near other blood that I had received in the bottom of a basin, and which was becoming black from the absence of air. In less than an hour the surface of the latter assumed a red color, while the former retained its blackness for several days. . . . To blood that was blackening in consequence of the application of spirits of vitriol, I added liquor of fixed nitre, but without producing any particular effect. The intense blackness became indeed somewhat diminished, but a color succeeded more of an ashy than a red cast. . . . If spirits of nitre, or alum either in a crude or burnt state, be mixed with the serum of the blood, they turn it into an extremely white coagulum; which object is indeed accomplished more readily by the addition of alum, which also forms a thicker and more tenacious coagulum. But if the serum were much colored, it would be proportionably less white when the above substances were added to it. A like result takes place on the application of salts of Saturn, but in a far more imperfect manner, because the whiteness produced is much more obscure, the mass does not become so thick, and a precipitation is rapidly effected. Spirits of salt do not coagulate the serum, but render it more limpid. . . . Spirits of vitriol turn the coloring particles blacker, but in other respects leave the mass but little changed. These experiments I made upon the blood of the ox. But I afterwards tried them upon blood taken from a man in a state of good health. In this case I did not observe the changes



to be so considerable, although they were of the same character. The red part of the blood, for instance, assumed a less degree of blackness from spirits of vitriol, and a less degree of whiteness from spirits of nitre, and so forth. . . . The serous part of human blood, in its pure state, . . . on slight boiling acquired a white color, and became almost as thick as the albumen of a hard-boiled egg. On the addition of alum it also coagulated, and on the addition of spirits of nitre was rendered milky, but did not acquire so thick a consistence, as did the corresponding part in the blood of the ox. . . . I have observed in regard to the blood of different men and oxen, that vinegar darkens the coloring particles, but in a less degree than spirits of vitriol. In other respects vinegar produces no alteration in the blood. Sea salt and nitre do not change it, except that they render the coloring particles when of a dark hue, bright and shining. This takes place however in so slight a degree, as to be noticeable in only a few instances. Fixed alkaline salts scarcely alter the blood at all. Blue vitriol slightly coagulates the mass, and gives it a greenish-white tinge. Green vitriol only renders it slightly turbid, and does not coagulate it; and in fact less change is produced by the addition of artificial vitriol, commonly called salt of steel, than by the addition of natural vitriol. Spirit of vitriol together with sea salt or nitre, when added to the more serous portion of the blood, produces a white coagulum; but the result is more complete with sea salt than with nitre. Spirit of salt in combination with sea salt or nitre produces a similar effect: but spirit of nitre is more efficacious than either of the other spirits, and produces this effect by its own virtue alone. Spirits of salt or vitriol together with alum prevent the effect produced by the alum, the mass which would have been coagulated by the alum alone, being rendered only slightly turbid. Nay more, the coagulation produced by the alum is removed by the addition of these spirits. Spirits of nitre and alum produce almost the same effect, whether they be used simultaneously or separately. Fixed alkaline salts prevent the effect produced by spirit of nitre; so that by a previous addition of the former, no coagulum is produced by the latter. . . . In fact, the coagulum produced by the spirit of nitre is dissolved by salts of the kind, and the mass again rendered limpid. . . . On taking a portion of blood and submitting it to a microscope, I have seen in it particles of different forms. Some appeared to be very long and in a manner tapering, like little stems of hay or straw; intermixed with these appeared others of extremely small length, and amongst them many globular particles. Some appeared to have three, four, or more sides, and to be of a very irregular figure. Of the globular particles a few appeared to be perfectly spherical, but the greater number



were of an oval figure, and some appeared to have an uneven surface. . . . In a portion of the washings of blood, that is to say, in water that had been used to extract the color from a coagulum of blood, a quantity of very various particles likewise appeared. By far the greater portion of them was globular, but the larger and more branching particles observable in blood itself did not here make their appearance. . . . In the gelatinous part of some blood received into a basin,—in the part that had spontaneously separated from the rest, and been further purified by frequent settling and decantation, and that was liberated from the redder and thicker portion,—we found particles of different kinds, but the globular ones were not in such numbers as in the water in which blood had been washed. . . . I put into a common sea-water bath the warm blood of an ox, received from its body in a cupping glass. The first liquor that came over was not in large drops like water, but presented a certain appearance of striæ. When collected it was very thin and limpid, almost tasteless, of a somewhat unpleasant smell, though not positively fetid, and if live coals were thrown into it, they were not so rapidly extinguished as in water. One table-spoonful of the liquor mixed with a few grains of salt of Saturn, acquired the color and consistence of milk. As far as I have been able to collect from the above circumstances, this liquor was composed of a large proportion of phlegm, a certain quantity of sulphur, and a little salt. This salt was of a mild taste, and did not appear to have any of that sharpness that volatile salts always have, which are expelled by a strong heat from any compound in which they are contained. The liquor that next came over was more watery, but none was elicited that was not rendered turbid and whitish by the addition of salts of Saturn,—an evident sign that this liquor was not phlegm, since the latter is in no degree disturbed by the addition of these salts. By this method I could not elicit any considerable quantity of humor, and when more ceased to come, I transferred the cupping glass to a sand bath, and raising the heat, obtained a liquor more impregnated with volatile salt and sulphur, but somewhat empyreumatic or burnt. The more watery portion being thus removed, I distilled the remainder in a retort over a reverberating furnace, and again extracted from it, first of all and before the heat became great, a very watery portion, and then a subtle penetrating liquor exceedingly pungent in taste and smell, and not a little efficacious in promoting perspiration, such in fine as is commonly called the spirit of the blood. Next followed a volatile salt, then a thick and fetid oil, and a caput mortuum, or most earthy part remained in the retort, and could not be made to pass, by any degree of heat, into the receiver. The salt however which is thus elicited is more volatile and active than the spirit

itself. Hence in the process of rectification it is the first to come over, although in the first distillation it is with difficulty expelled, on account of being much implicated with other particles, and does not begin to make its appearance till after the phlegm and a large portion of the spirituous liquor. . . . I do not think I am very wide of the mark if I say, that in seven ounces of human blood . . . there are five ounces and six drachms of water or phlegm, three drachms, or a little more, of a subtile oil or oily spirit, about eight scruples of a thick oil, about two drachms of salt, (almost all volatile, or at least easily volatilized, whence I consider it volatile,) and a little more than two drachms of earthy substance." (*Corp. Hum. Anat., sive Supplement. Anat.*, lib. ii., tr. i., cap. ix., p. 29—37. Bruxell, 1710.) Further remarks on this subject may be seen in the author himself.

35. The reader would consider it tedious were I to bring forward all the experiments and observations made upon the blood by every author. I may, however, adduce the following. Alkalies impart a red color to milk, and this redness is heightened by the application of sal ammoniac, nitre, borax, rock salt, sea salt, regenerated tartar. Vitriolic acid diluted in water retards the coagulation of the blood, but nevertheless afterwards coagulates it and imparts to it a black color. Moselle, the Rhenish wines, and wine vinegar heighten the red color of the blood, and impede its coagulation. The serum of the blood is not coagulated by the juice of limes. Arterial blood coagulates sooner and is more florid than venous blood; venous blood escaping through a small orifice into a large vessel is like arterial blood. Certain insects and marine animals have white instead of red blood. Blood taken from the arteries is almost of a uniform color from the top to the bottom, but taken from the veins it appears black towards the bottom. Blood well shaken up, forms fibres, and these fibres, membranes. The sanguineous clots in a frog that has been frozen, are not resolved by heat, but by the motion of the heart. The blood which is found in the right side of the heart of a hungry animal has not an alkaline or an acid taste, but savors rather of ammoniacal or sea salt. Blood treated with acids and alkalies, does not manifestly effervesce, but changes its color and degree of fluidity. Blood spirting from the cut apex of the heart does not bubble or effervesce; nor is the blood perceived to be any warmer in the heart than elsewhere, according at least to the indications of the thermometer. The chyle in the thoracic duct tastes of sea salt, and when salts are applied to it no ebullition ensues. Baked and pulverized blood, when placed in warm water, separates into a red matter, an insoluble and a soluble glutinous substance. One cubic inch of blood is expanded by distillation into a vapor occupying the space of



33 cubic inches. One cubic inch of fat is by distillation converted into a vapor occupying the space of 18 cubic inches. Blood placed in an exhausted receiver grows purple, and sends up bubbles to the surface. Its serosity emits bubbles sideways in a vessel, which gradually assume a direction toward the surface. The froth and bubbles continue for 24 hours. Still the mass does not swell much, but very gradually increases about one-third. Recent blood, whether taken from the veins or the arteries, yields clot, serum, and a saline exhalation. For if cruor be received from a vein into a small vessel, in a short time the whole forms a coagulum like that of goats' milk; by and by its red part contracting equably toward the centre of the vessel, gradually conglutinates into a fibrous but yielding network, in the areolæ of which are contained a limpid ichor and red globules. In a short time it expresses on all sides a liquid or serum, which concretes by the addition of acids, spirits of wine, and especially by being submitted to heat; if, moreover, it be suffered to digest awhile over a slow fire, it becomes almost as hard as cartilage or bone. In the mean time each of these parts, or that which spontaneously concretes, and that which remains fluid, in proportion as it grows warm, emits a halitus or vapor, which is pungent both to the nostrils and tongue, but is of no particularly strong odor or taste. If this vapor be received in a closed glass vessel, it generally condenses into a cloud and dew, of the urino-volatile nature of which there can be no doubt. If small lumps of clotted blood be thrown into their own serum, they do not swim, but sink to the bottom, and this with the greater celerity the nearer the slice is cut off from that portion of the coagulated blood which is the blackest and lies at the bottom. In consequence of disease, however, it may happen that the coagulated part of the cruor is found specifically lighter or heavier than the serum itself. See the French Commentator upon Heister,\* also the writings of Lancisi and others.

\* *L'Anatomie d'Heister, avec des Essais de Physique sur l'Usage des Parties du Corps Humain, &c.* [par M. Jean Senac]; 8vo., Paris, 1724; Ed. 2, 1735.—(*Tr.*)



#### INDUCTION.

36. THERE is a certain fluid of the highest degree of purity, called by some the animal spirit, which enters into the red blood as its principal substance, and which constitutes its vital essence. There likewise appertain to the red blood in different proportions numerous salts, which enter into the composition of its parts. Whence the blood exists as a compounded liquor, and is the ultimate fluid which discharges the functions of the soul in the animal kingdom.

The red blood is surrounded with serum, to which we are to ascribe all the components of which the blood is constituted and formed. With a view to the composition of the blood, there are conveyed to the serum through the medium of the chyle, and in water as a vehicle, spirits, oils, and salts of every kind; also, through the medium of the air, and by help of the lungs, the nitrous and volatile substances that are fluent in the atmosphere; and finally, through the medium of the ether or purer air, substances still more volatile: with each of which unless the blood were replenished, it could not be prepared and renewed for the various uses of the animal economy.

The blood therefore is the storehouse and seminary, the parent and nourisher, of all the parts of the body, both solid, soft, and fluid; for nothing exists in the body which had not a prior existence in the blood. Wherefore upon the nature, constitution, determination, continuity, and quantity of the

blood, depend the fortunes and condition of the animal life. In the blood therefore we are to look for the cause and the mode\* of that natural life which is led and continued in the body and in the ultimate world.

But inasmuch as the blood exists and subsists from so many substances and elements out of this mundane system, the qualities of which are hitherto unknown, there is no hope of perfecting a science of the blood without exploring in genus, in species, and in their several parts, the nature of the mundane auras, the aqueous elements, the oils, spirits, the salts whether fixed, volatile, or essential, and the sulphurs. To this we must add a knowledge of the causes of heat, fire, flame, cold, and colors, together with all the other subjects of experimental chemistry and physics. Nor is this sufficient, since the science of the blood extends also into the fields of physiology and of pneumatology, or the function of the animal spirits.

From an attentive consideration of these things it may in some measure be evident, that the spirituous fluid constitutes the essence of the life and activity proper to the blood, from which spirituous fluid there exists, through the medium of a copious volatile substance derived from the ether, a pellucid or middle blood. Lastly, through the medium of fixed and urinous salts employed in tempering, copulating, determining, and finally, perfecting the composition, there emerges the red and heavy blood. Into these original principles this latter kind of blood suffers itself to be divided according to degrees during its progress through corresponding vessels, or those first of a like order with itself, then through the capillary tubes, and lastly through the fibres.

Hence it follows that in the composition of the blood we have to take into consideration three degrees, which indeed are perceivable distinctly one from the other, inasmuch as the

\* Cur et quomodo.



blood is compounded of each distinctly, and into each is distinctly divided. Blood in the last of these three degrees ought to consist, for the most part, of six plano-oval spherules, which fit themselves into so many hollow sides of a single particle of fixed salt. Whence arises the spherical figure of the whole.

But although the spirituous substance of every animal enters into all the genuine blood of the animal as its principal and only vital substance, nevertheless in every species of animal the blood is different, and varies in the individual subjects of every species, according to temperaments, states, and ages. Moreover there is both legitimate and spurious blood according to the health of the body.

With respect to the first substance of the blood, or the spirituous fluid, and with respect to its other substance, or the purer blood, it is to be observed, that each in its own degree is most highly elastic, most highly susceptible of consociation, plication, as well as of reduction into every form. But into whatever form it is reduced, it naturally aspires to its most perfect form, and is in the effort to return to it; it is moreover endowed with such perfect fluidity, and is so capable of acting according to every mode of an efficient cause, that in these respects nothing can surpass it.\*

In the last or ultimate composition, which is the blood properly so called, exist the same qualities, but more imperfectly in accordance with the degree of composition.

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Each of the clauses of this general induction, which furnishes the argument of the present chapter, we now proceed to examine separately.

\* *Estque ita ad omnem fluiditatis naturam, et causæ efficientis modum qualificatus, ut in eâ re nihil utrumque superet.*



37. *There is a certain fluid of the highest degree of purity, called by some the animal spirit, which enters into the red blood as its principal substance, and which constitutes its vital essence.* At this the very outset of our inquiry respecting the blood and the economy of the animal kingdom, we find presented to our notice a certain fluid of a most perfect and refined nature, which runs through the most diminutive and attenuate vessels, stamina, and fibrules, and which traverses and supplies with moisture every living point and corner of the body. Whether this be what is called the animal spirits, it is not the place here to consider. The subject may be found discussed in Parts III. V. and VI., on the Cortical and Medullary Substances of the Brain, and the various parts of its chemical laboratory.

38. As I cannot here enter into the particulars contained in those Parts, it is of importance that I should lay before the reader the principal points they contain. *First*, it is shewn, that such a spirituous fluid as we have just mentioned, is interiorly conceived in the cortical and cineritious substance of the brain, the medulla oblongata and medulla spinalis; that it is next emitted into all the medullary fibres or origins of the nerves, and is thence ultimately derived into the blood; that it is poured, for instance, by the brain through the pipes which belong to its laboratory, such as those of the ventricles, infundibulum, and other organs, into the sinuses, thence into the jugular veins, and thence into the subclavian, just above the place where the chyloferous or thoracic duct is inserted. It is shewn, that the spirituous fluid is carried hither, in order that being immediately associated with the chyle or lymph which is conveyed through the thoracic duct, it may flow into the right side of the heart, and that in this great conical mill, which is ever at work in receiving and commingling the sanguineous current, it may, with the other elements which are imported by the veins from the inferior extremities, concur in creating blood. *Secondly*, that the same fluid also is carried downwards from the cerebrum, cerebellum, and their medullary appendices, along the fibres of the nerves, into all the provinces and little districts of the body, and that it terminates its progress only in the blood-vessels, which are its ultimate boundaries. For in

the body nothing can be found more perfectly conjoined and more universal than fibre and vessel, as the one enfolds the other, and both are in such intimate consociation, that the vessel lives continually from the spirit which belongs to the fibre, and which in its state of union with the vessel the fibre exhales into the blood. *Thirdly*, hence it follows, that there is a certain circulation of the fluids of the body more universal than the circulation of the blood through the arteries and veins; and which so far as I know has never been fully investigated and developed by any one; namely, a circulation from the fibres into the vessels, and from the vessels into the fibres.

39. This subject however, which is of the utmost importance and deserves a voluminous explanation, ought not to be lightly dispatched; but as we cannot here enter more at large into its consideration, the reader must be content for the present simply to keep in mind the leading points I have just enumerated, since they are necessary to a right understanding of the remarks I have to offer, and since without some such general idea as that I have given, he would not be justified in presuming that such a fluid enters the blood and constitutes its vital essence. Still it is my wish that the positions above enumerated, should be placed, before they are confirmed by actual fact, on the ground of simple hypothesis, or they may be expressed by the sign of the unknown quantity  $x$ , as in the algebraic analysis, until it be clearly ascertained whether or not the additional data will elicit its value.

40. From the facts which we have premised at the commencement of the present chapter, the only inference we at present consider ourselves at liberty to make is the following. That the red blood is divisible into a purer transparent blood; and next into a most attenuated fluid, which on account of its subtilty is not perceivable to the eye. According to Leeuwenhoek, one globule of blood is compounded of six smaller ones. He relates that he had subjected the larger globules to violent motion, when they burst in pieces, and displayed the smaller globules. Also that in a tadpole, a hundred thousand myriad of the blood particles could not equal in bulk a large grain of sand (n. 29). And Gulielminus quotes from the



same author, "that the plano-oval particles are not only separated from each other in the capillary vessels, but are even comminuted into others which are smaller and colorless" (n. 32). "It is difficult to ascertain," says Boerhaave, "how far the division into lesser globules proceeds" (n. 31). From this division, however, we may infer the existence of a certain most subtile essence, or as it is called, quintessence, capable of running through the very fibres of the nerves and interiorly wedding itself to the blood, inasmuch as when the blood is resolved into its constituent parts, we find this essence rushing out as it were from its bosom. We arrive at the same conclusion by induction from those data which simply describe the more occult qualities of the blood, as for instance, those of its fluidity, flexibility, volatility, and vitality; for whatever the blood possesses, it contains inwardly in itself, and does not derive from any other source than from the forces and substances which have their being within it. With respect to the *fluidity* of the blood, this you will see treated of in the Chapter which follows, on the subject of the Arteries and Veins. With respect to its *flexibility*, this you will see treated of in n. 100 of the present chapter. With respect to its *volatility*, Verheyen says, "The more watery portion [of the blood] being . . . removed, I distilled the remainder in a retort over a reverberating furnace, and again extracted from it, first of all and before the heat became great, a very watery portion, and then a subtile penetrating liquor exceedingly pungent in taste and smell, and not a little efficacious in promoting perspiration, such in fine as is commonly called the spirit of the blood" (n. 34). From this we infer, that there is a kind of volatile fluid incorporated with saline particles, which is exhaled especially from recent venous blood; not to mention many other circumstances, all tending to shew that the blood is full of a certain fugacious spirit. With respect to *vitality*, let us hear Harvey: "There is reason to doubt," says he, "whether before [the heart and even the auricles pulsate] the blood itself . . . has not in it an obscure palpitation, such as I have seen it retain after death" (n. 246). And again: "First of all there is in it [*i. e.*, the egg], a drop of blood, which palpitates, . . . and from which . . . are formed the auricles of the heart, and in



these, which perpetually pulsate, the life resides.” (*Ibid.*) This phenomenon the reader may see treated of in Chapter III., on the Rudiments of the Heart, &c.

41. That the blood is a concrete of substances of various natures, and more especially of the fluid in which the soul resides, and of which the soul is the life, is a subject which the reader will see further explained in our subsequent articles. The first general idea which commonly suggests itself to the mind in regard to the essence of any object, is also the one which we find suggested in the present case of the blood, as for instance, that it is a vital and most spirituous fluid which is in immediate connection with the soul, as is well known, at least, in the case of brutes. This idea the mind cannot help forming when judging from the phenomena presented to its notice, and finding that there is nothing which has a more intimate presence in the animal kingdom, and a greater degree of potency, than the blood; nay, that from changes of its state results are produced which affect the very sphere of the thoughts.

42. If experimental fact shall explain or clearly evolve this theorem, which hitherto has been only involved, it will diffuse a remarkable degree of light over the whole economy of the animal kingdom as well as over the subject of psychology.

43. *There likewise appertain to the red blood in different proportions numerous salts.* According to Lancisi, the following principles may be separated from the serum and crassamentum by distillation: “1. Urinous phlegm. 2. Volatile salt, of which with a small proportion of phlegm a spirit is composed. 3. A yellow and a black oil. 4. An ash or earth in combination with saline particles” (n. 30). Verheyen supposes, that “in seven ounces of human blood, . . . there are five ounces and six drachms of water or phlegm, three drachms or a little more of a subtile oil or oily spirit, about eight scruples of a thick oil, about two drachms of salt, (almost all volatile, . . .) and a little more than two drachms of earthy substance” (n. 34).

44. That the parts of the blood, which are described as spherical, are not simple and indivisible, but compounded of various salts, is a fact which may be proved by a variety of processes beside that of distillation, such as digestion, fermentation, purification, extraction, solution, luctation, and muta-

tion when the proper menstrua are employed ; while on the other hand, there is no appearance of any mutation of the parts of the blood when media are used which are in harmony with its nature. Beside these proofs we may add others arising from the odor of the blood, its taste, color, warmth, the strepitus it occasions when submitted to the fire, its weight, its tendency to concrete into fibres, reticular areas, striæ and pieces, and its privation of these qualities when decomposed ; also from the nature of the serum ; from the food that is received into the system, and so forth.

45. That the salts which enter into its texture are marine, urinous, and most highly volatile atmospherical salts, is abundantly testified by the well devised and admirable experiments of Boyle, Boerhaave, and others. *Whence the blood exists as a compounded liquor.* “The red blood,” says Boerhaave, “is the grossest of all the humors that a state of health nurtures and cherishes in the viscera, arteries, and veins” (n. 31).

46. *And is the ultimate fluid which discharges the functions of the soul in the animal kingdom.* This is the definition of the blood while acting as the life of the body ; another and generic definition the reader will find in the sequel. There are liquids in the body perhaps still denser than the red blood, such as crude or imperfect chyle, saliva, fluid fat, bile, semen, &c. Still however these do not carry on the functions of the soul, as a continual cause, like the blood, which creeping along all the sinuous passages of its kingdom, and being everywhere present with its spirituous essence, extends its influence even to the fibres, as already has been stated in n. 37. In order that the soul may descend into the body, and become an agent in the ultimate or lowest sphere of action in the world, and since it cannot become so immediatly or without a medium, we find that it subordinates to itself such a fluid as will coalesce by successive gradations, and which having attained its due consistence and adequate conditions, can serve as a dwelling in which the soul may reside. Hence you may call the blood the *soul of the body*, and if you please, the corporeal soul.

47. *The red blood is surrounded with serum.* In their larger acceptation both are taken for blood, because in the arteries and veins, they maintain the strictest union, but when drawn



out from these vessels, they separate from each other; the serum ascends to the top, the red portion occupies the bottom. The serum appears limpid like water, sometimes a little turbid, of an opaline tint, yellowish, having a tendency to green, sometimes also it is grey.\* The red portion, on the other hand, becomes purple, a deep red, sometimes brown, of a rusty hue, rather dark, or of the color of bile. The serum sometimes is thinner, sometimes thicker, but is condensable by heat. The red portion has more of tenacity, and spontaneously congeals in the cold, whence it turns into crassamentum as it is called, and at length becomes so solid as to be capable of being cut with a knife. This crassamentum sometimes overlays itself with a crust, which is generally said to be a gelatinous substance and concretable serum. "The proportion . . . of . . . elementary principles in the serum," says Lancisi, "is different from what it is in the crassamentum, since in the serum the aqueous part, and the part consisting of volatile salts, is more abundant, but the earthy, the fixed saline, and the oily parts, more scanty. On the other hand, in the crassamentum, there is less of the liquid part and more of the other parts" (n. 30).

48. *To which we are to ascribe all the components of which the blood is constituted and formed.* The serum is as it were the atmosphere in which the blood flows, and from which it derives its elements; wherefore such as the serum is, such is the blood arising from it, and such as is the blood, such is the serum. This we see exemplified in the various animals, which by the instinct of nature, know how to distinguish their own proper food; that is to say, food of such a quality, as their blood, their spirituous fluids, and the concrete substances produced from them, require. For this reason it is, that between the serous and red portions of the blood there is so great a similitude, affinity, and as it were matrimonial compact; or that one is on terms of such intimate union with the other; the end in view being the constitution of blood, and the intermediate leading to this end, the circumfluence of a suitable fluid out of which blood of a proper nature may be formed. Thus

\* Cæsium.

the end provides the means, and one cause conjoined with another begets the effect.

49. *With a view to the composition of the blood, there are conveyed to the serum through the medium of the chyle, and in water as a vehicle, spirits, oils, and salts of every kind.* For in the various kinds of food which we eat and drink, there are contained three well-known principles, namely, spirit or oil, salt and earth, and water or phlegm, each of which may be disengaged by a moderate chemical heat. This indeed is more clearly shewn in the stomach, which is a sort of beautifully coated chemical bladder and retort of animal nature, in which, as the food is received, comminuted, and subjected to trituration, is effused the vital extract,\* or salivary liquor, endowed with most exquisite properties, and animated by a spirituous essence. From this organ the chyle, according as it is prepared, traverses its milky way into the thoracic duct, next into the left subclavian vein, and thence rapidly into the jugular vein, where it is met by the genial spirituous essence arriving from the brain. This chyloferous duct, whenever it is not supplied by its own milk, or by the juice expressed out of the esculent substances in the stomach, serves as a vehicle for the depurated lymph returned from the arteries. Thus it is that the elementary principles above mentioned, are conveyed to the blood in water as their vehicle; and thus also it is that we find the same things in the serum which we find in the blood, the qualities of both being capable of being explored and laid open to view in a thousand different ways (n. 43, 44).

50. *Also, through the medium of the air, and by help of the lungs, the nitrous and volatile substances that are fluent in the atmosphere.* With regard to the air itself, the little pulmonary follicles eject and vomit forth at their arterial extremities whatever portion of it has been conveyed to them, as injurious to the blood, nay, as a most mischievous inmate, a mere menial attendant of the cruder chyle, and an incarcerated foe. While, on the contrary, the open mouths or extended lips of the little veins, seize and immediately suck in the atmospherical salts which agree with them, and are attracted to their mouths at every in-

\* Flos vitalis.



spiration.\* This I shall endeavor to evince, from the structure and continuity of the bronchia; from the recipient diminutive cellules and pouches of the lungs; from the ends and beginnings of the little arteries and veins which are there; from the smell and vapor of expired breath; from the phenomena attending the process of sanguification in the lungs, and in young chicks enclosed in the egg before the initiaments of the lungs appear; from the exclusion of air in the primitive formation of the viscera; from the change which takes place in blood when exposed to the air, and which is similar to that produced when tinged with the nitrous and the urinous grateful effluvia with which the atmosphere abounds; from the state of the blood, which changes with the state of the air, with the seasons of the year, and with the state of the lungs; from the nature of nitre as compared with the nature of the blood; from the vast ocean of those nitrous halitus which are confluent in the atmosphere; from the structure of the right ventricle and auricle of the heart, as compared with that of the left; and from many other particulars, to be found in Part VII., on the Tongue, the Trachea, and the Lungs. "Six ounces of nitre in solution," says Malpighi, "introduced into the jugular vein of a dog of middling size and strength, produced no sensible change, except an abundant secretion of urine; in other respects the animal continued in perfect health. . . . When powdered nitre, or nitre dissolved in water per deliquium, is placed upon blood, it produces upon the surface a thin substance of a deep crimson color, and the same occurs when aqua vitæ, common salt, rock salt, sal ammoniac, sulphur and hartshorn are made use of in the same way. Nearly all these substances appear to retard the coagulation of the blood for a short time" (n. 33). And again he says: "There is reason to believe that nature, in her solicitude to maintain the fluidity of the blood, is constantly pouring on it . . . a certain fine and highly active principle. . . . This salt of life is eliminated by the lungs by means of fermentation, either from the liquids brought by the blood, and particularly from the lymph; or as I incline to think, from the external air, since the lungs themselves are analogous to glands in structure." (*Ibid.*)

\* Per inspiratum attractos & visco accubio inescatos.

51. The case may be illustrated by considering the lungs as a single stomach consisting of an infinite number of smaller ones, but feeding on aërial food, just as the stomach properly so called feeds upon terrestrial food prepared out of every kind of edible substance. Hence both the stomach, and the lungs which we have here considered as a species of stomach, contribute to the support of the blood.

52. We are not to conclude all that to be air which rises in bubbles, or expands in the blood when placed in an exhausted receiver, and from observing which some have been led to assert the presence of air in the blood; nor all that to be air which produces bubbles in water, oil, spirit, soap, and fluid metals while heating over the fire, exhibiting subsultory motions and undergoing complete evaporation. The real nature of the substance which thus escapes, I shall have a future and better opportunity of explaining.

53. *And finally, through the medium of the ether or purer air, substances still more volatile.* This is a theorem, in the demonstration of which a merely particular branch of experimental knowledge, and much less the small portion of it with which I have commenced the present chapter, affords but little light. It is one, however, which may be solved by help of a general experimental knowledge, or a complete proficiency in the anatomical, physical, and chemical sciences, inasmuch as the demonstration of the theorem reduces itself to a proof of the following propositions.

54. First: That there exists an Aura purer than the common air; as the reader may see confirmed in n. 67 and 68, and in Chap. VIII. of the present Part.

55. Secondly: That this Aura contains the most volatile substances of nature, in like manner as the common air contains those which are grosser. That there exists a certain purer air full of elements saline and sulphurous, and that we are surrounded by an ocean of insensible effluvia, is a fact discovered to us by a variety of circumstances; such as by the sagacity of certain kinds of animals; by phosphoric substances of every kind, and ignes fatui; by the exhalations of magnetic substances; the internal commotions observed when different menstrua are mixed together, though excluded from the air by partitions of wood



and glass, as when they are placed under an exhausted receiver; by the continuation of life though unsupported by food, for weeks, months, and years, as is the case with cameleons, vipers, hybernating bears, swallows, insects, &c.; nor are there wanting examples in the human species of a similar exemption from thirst and hunger. Also by contagious diseases, which so communicate the pest and poison of their nature as to vitiate the blood, and injure, badly construct, or disunite, that compages of its parts which is formed by the orderly coalition of its most minute particles. To these circumstances we may add the phenomena of perspiration as discovered by Sanctorius, the vegetation of numerous plants merely in common air, not to mention many other things; all tending to shew, that there is a larger store of alimentary substances which are imperceptible to the senses, than of those which are perceptible. On which subject the reader will find it worth his while to consult the works of Boyle and other authors.

56. Thirdly: That the outward skin eagerly seizes, and through its insensible pores imbibes from the common air, numerous substances, for the purpose of concocting and renewing the blood. This may be inferred from the texture of the parts constituting the extremities or universal surface of the body; from their transmeability; from the hungry avidity with which they absorb contiguous and approaching substances, particularly at those periods when the body lies awake for nights and days, and the thirsty little veins are expanding their mouths within their organic cellules.

57. Fourthly: That the whole, together with every particular part in the body, thus eagerly desires the treasures of the surrounding world, with a view to the prolongation of its life. There is nothing, indeed, which does not administer to the support and perpetuation of the functions of the animal kingdom; and this, to the end, that man may become a microcosm or little world, and may subsist as a compound of all the elements of the mundane system, according to the opinion of the ancients. From these observations follows the truth of the next clause,—*with each of which unless the blood were replenished, it could not be prepared and renewed for the various uses of the animal economy.*

58. Here we find a problem suggested worthy of investigation; namely, whether, since an animal can live and renew its blood solely from atmospherical sources, without the reception of its ordinary food, (as in those instances in which for the whole or a great part of their lives animals go without food, or in which they for a long time silence their appetites by a state of slumber and torpidity,)—whether, I say, the cause of this circumstance may be, that as a state of wakefulness of the organs of the senses, the consequent excitations of the animal mind, and the muscular actions, open the lacteal and close the aërial passages, so a state of sleep, insensibility, and inaction closes the former and opens the latter; and whether, as soon as the voluntary and rational mind descend into the sensitive and active life of the body, it is for this reason that the use of the stomach, and a reparation of the corporeal soul, or the blood, be each of them required?

59. *The blood therefore is the storehouse and seminary, the parent and nourisher, of all the parts of the body, both solid, soft, and fluid, in its own kingdom; for nothing exists in the body which had not a prior existence in the blood.* All the substances, for example, that enter into the texture and continuous\* parts of the body, pass into them through the sanguineous passage; their ingress is through the veins, their egress through the arteries. Between the channels of ingress and egress lie the heart and lungs, each of which is traversed before the ultimate place of destination is reached and the route completed. Whatever issues through the extremities of the little arteries with a view to form the texture of the part which is to cohere, has first been converted into blood; but the substances which are to be ejected from the system, such as urine, mucus, and sweat, seem to have had their residence solely in the serum, and thence to have been endeavoring to intrude themselves into the blood.

60. The passages that lead into the venous blood are three; namely, one from the common stomach, continued through the intestines; a second from the compound stomach of the lungs; and a third from the skin; as shewn in n. 49, 50 and 56. Again, the passages which lead out of the arterial blood

\* Continentem.



into the system are three ; namely, glands, vesicles, and pores ; an abundance of which we meet in every structure. The substances however which are rejected from the system as useless, obsolete, and old, escape by the urinary bladder, the bronchial ducts, and perspiratory skin ; while those which are carried either inwardly or outwardly with a view to any use, such as saliva, milk, semen, &c., make their exit at their several periods through outlets which are respectively proper to them.

61. That all the substances which enter into the composition of the body, travel this liquid path ; that for instance they make their entry by their appropriate inlets, gain the midway goal, and speed their course thence, in order to coalesce or become fixed in some different manner, is evidenced by the absorbent mouths of the veins and the secreting mouths of the arteries, which we everywhere find at the boundaries of the sanguineous system ; by the transmeability and perspirability of all the parts of the body ; by the universal presence of vessels, and their extension through all the larger areas and minuter corners of their kingdom ; by the unceasing circulation of the fluids ; by the numberless receiving vessels for the lymph ; by the constant inosculation and adaptation of parts ; by the perpetual chemical action going on through the whole system ; by the nature of the concrete parts, which is seen to be similar to that of the blood and its serum ; by the fluidity of all the parts previous to their consistency, or by the fact that the law according to which they solidify, is founded on the law of their action as fluids, and the law by which they subsist is founded on that by which they exist ; by the process of induration and putrefaction ; by states of torpor, swooning, or death, resulting from the want of a due supply of blood ; by the whole pathology of the body and mind ; and finally, by the cautious and provident manner in which the blood selects its various subsidies out of the wide domains of the mundane system. Whether however any portion of the nervous fluid is instilled immediately into the blood out of the fibres and extremities of the nerves, previous to their entrance into any vessel, is a question which, as we have yet no experimental facts upon which to reason, may be considered to be still involved in doubt.

62. *Wherefore upon the nature, constitution, determination,*

*continuity, and quantity of the blood, depend the fortunes and condition of the animal life.* This indeed is abundantly manifest from the various ways and means of preserving and recovering health, or from the study of medicine, considered in its largest acceptation. For the drugs which the apothecary sells and the physician prescribes, have almost all a reference to the restoration of the proper state of the blood, which is the fountain of life, and consequently of those sciences which have the perpetuation of life for their object. It is manifest from the *nature* of the blood, for every species of animal lives the life proper to the specific nature of its blood; and not only every species, but every individual of that species; every difference whether of species or individual, implying a corresponding difference in the blood. It is manifest from an alteration in the *constitution* of the blood, in which case a corresponding alteration is produced in the general system, as we see in every instance in which nature is departing from her ordinary rules. It is manifest from the *determination* of the blood; for this determination is accomplished by means of the vessels, which are so many ways and directions of its determination, and from the profound combination of which is educed that astonishing organism and mechanism of the body which is in correspondence with its chemical and physical operations. It is manifest from the *continuity* of the blood; for it is from this continuity, and the reciprocal connection between the components, that a unanimity of action in the system is produced; that the whole lives the life of the part, and the part of the whole; and that not a single thing exists in the body, that is not at once obedient to the brain, and in a state of mutual dependence upon other things. It is manifest, lastly, from the *quantity* of the blood; for from this source arise plethora, obstruction, atrophy, symphysis, synexosis [?], ceneangia, diapnoë, anastomosis, diapedesis, diæresis, and every other malady arising either from a superabundance or deficiency of blood.

63. The nature, constitution, determination, continuity, and quantity of the blood, may be considered as five common relations or varieties, which multiplied one into the other, furnish so many general causes of change in the body, or so many different conditions under which the blood may exist, and which



are soon found to exceed a hundred. Hence it follows, *that it is in the blood that we are to look for the cause and the mode of that natural life which is led and continued in the body and in the ultimate world.*

64. *But inasmuch as the blood exists and subsists from so many substances and elements out of the kingdoms of this mundane system, the qualities of which are hitherto unknown, there is no hope of perfecting a science of the blood.* Let it be granted, that the several parts of the red blood comprise salts of each kind, and at the same time a fluid of the highest purity; let it also be granted that these several constituents readily coalesce, and that each occupies its relative place in the exactest order; nevertheless, if we continue in profound ignorance of what that spirit is which is indigenous to the blood, what is the nature of the fixed and volatile salts, &c., and what the manner in which the parts in so small a spherule are respectively conjoined, must not our ignorance of the nature of the essentials conceal from our knowledge the nature also of the accidents, and must not the part itself together with the whole remain involved in obscurity? Whenever therefore we say that we know this or the other component to exist in the blood, while nevertheless the nature of the component continues unknown, are we not amusing the mind with the mere shadows of things, and feeding upon empty sounds, signifying things incomprehended? When a name which is given to any unknown quality becomes familiar to us, we are apt to think, after a frequent use of it, that we clearly understand the nature of everything it comprehends. But if in such cases we only ask ourselves, What is this? Whence is this? and if we persevere in the question, we shall find that instead of going forwards, we have only been retrograding from things more known to things more unknown, and from these again to others most unknown. If, therefore, we have any desire to become acquainted with the more interior qualities of the blood, we must institute a scrutiny into its constituents individually.

65. *Without exploring in genus, in species, and in their several parts, the nature of the mundane auras.* What the auras effect in any animal appears from the consideration, that without auras, it could neither as a whole nor as to any of its parts sub-

sist, or move ; that without auras, the sense of hearing could distinguish nothing, the eye could discern nothing ; nothing either in respect of magnitude or form could be held in connection ; every species of liquor would be torpid, even that which we preëminently call the animal liquor, and the very blood itself, whose modifications are in conformity with those of the auras. “When Leeuwenhoek examined blood possessing much crystalline liquor, and placed in one of his tubes, and carried it into the open air at a time when there was a pretty strong wind, he observed that the globules were agitated, like the air itself, by concussions and mutual motions” (n. 29). That even the organs of the senses have received a conformation in correspondence with the states of the modification of the auras, is a fact which is perfectly well known from the structure of the ears and eyes. Consequently, it appears to be owing to some circumfluent and interfluent aura, or ether, that the individual particles of the blood are permanently held together in their connection and form, and never experience any diminution of their motion. For from the moment the blood declines into a state in which it ceases to retain its higher aura, preserving only an air of some grosser quality, it begins to die, to separate from the serum, to be converted into clot, and to descend through states successively lower until it arrives at putridity ; in a word, until it has ceased to be alive. But here the question arises, What is air, and what is ether ?

66. The air and the ether, from what I have been led to conclude from the various experimental sciences, are auras or atmospheres of the mundane system, whose parts, (into which they are most distinctly divided,) are most perfect forms, receiving their determination according to the gravity and acting force of their dimension ; they are expansile, compressible, contiguous ; hence susceptible of modifications ; experiencing the least possible loss of any impressed forces ; most exactly representing the images or differences and proportions of impressions received in one place, at another, however remote ; having a tendency equally to every direction according to their force or gravity ; that is, from a centre to the circumferences belonging to it, or from these circumferences to the centre ; so that one and the same part can be in the centre, in the radius,



in any circumference belonging to the centre, or in a thousand of each at the same time. Of these auras, such as are the parts, such as are the volumes, and such as are the volumes, such is the entire atmosphere; so that a part of any atmosphere is its smallest volume. They are moreover, as it were, the forces of nature in their forms, to act as which they have a constant tendency. Such is the manner in which they constitute the circumfluous regions of the mundane system. But a question again arises, What is the origin of the air and the ether, and what the difference between them?

67. When the rational mind, from the effects presented to its notice, institutes an analytical inquiry into their causes, it nowhere finds them, except in a subordination of things, and a coördination of things subordinate. We must therefore travel through the orders and degrees of things, would we from the sphere of effects reach the sphere of causes, or ascend beyond it. To stop short on the road as often as anything occurs we do not comprehend, and to employ ourselves in supposing things simple and uncompounded as antecedents to other things of which we have only the same idea, is but prescribing so many ultimate boundaries to the human intellect, and destroying all chain of connection between consequents and their antecedents.

The forces of nature and the substances of the mundane system possess, not one, but many distinct spheres of activity, one under the other, each of which terminates in its own proper unity. Should any one of the inferior spheres be dissolved or perish, the superior spheres nevertheless outlive the dissolution; for whenever the effect perishes, still the cause survives; thus whenever air ceases its existence, the ether survives; when the red blood ceases, the spirituous substance survives; and when the body dies, the soul survives. What is superior may exist and subsist without what is inferior, as the parent without its offspring, the substance without the subject in which it resides. The converse however cannot obtain.

Would we know therefore what is the air and what the ether, we must distribute the auras into their several degrees; for example, into degrees, superior and inferior, or prior and posterior. Those which are superior and prior are also more

universal, less compounded, and more perfect, and are as it were the analogues of such as are inferior and posterior. Hence the air is one thing distinctly, and the ether another, in the same manner as hearing is one thing distinctly, and seeing another; nor is it possible for us to arrive from air at ether by any process of attenuation. That all other things in the mundane system, and its threefold kingdom, distinguish themselves into similar degrees and orders, the reader will see confirmed in the course of the ensuing chapters, particularly in Chapter VIII. of the present Part, in which I have entered upon an explanation of the Philosophy of Degrees.

68. Experience shews that the atmospheres or auras of the mundane system are of a fourfold order, namely, air, ether, and two others still less compounded. That there is such an atmosphere as *air* is proved by the phenomena of the air-pump; by the respiration of the lungs; by sound; by the organ of hearing, and an infinite variety of other things. That there is such an atmosphere as *ether* is proved by the science of optics; by the organ of sight; by color, light, and shade; by the exhaustion of the receiver of an air-pump; by the vast tide of insensible effluvia surrounding us, and penetrating vitreous and metallic bodies; by the forms and connections of the minutest atoms, &c. That there exist *atmospheres still less compounded* is proved by physiology; by the organization of the internal senses; by the mutual relation existing between the internal and external senses, and their dependence one upon the other; by the magnetic properties of things; by the fluxions and orbits of the celestial bodies; by vortices; by physico-astronomical science; by the correspondence between the gravities of bodies and their forces; by the causality of effects; and by the use of analogues as adopted by ontologists.

Without, however, that experimental knowledge to which I have before adverted, we cannot venture to explain the quality of each aura except in some such general terms as the following; as that the ether (n. 67), for instance, is prior to the air, more universal, less compounded, and more perfect; that the aura\* is of an order superior to the ether, and so forth. But enough

\* Preëminently so called.



I think has been said concerning the auras, so far as they relate to the blood.

69. *The aqueous elements, the oils, spirits, the salts whether fixed, volatile, or essential.* These all have existence in the blood (n. 43). A question therefore arises, what and of what quality they are?

70. In our investigations into their nature, let us begin with *common salt*, as standing at the head of the family of salts. Experience informs us, that the individual particles of sea salt have their birth in the water, or between the particles of the water, which are in shape rudely spherical, somewhat hard, and of themselves almost inert.\* This being admitted, it follows, that they are in the form of the interstices existing between the particles of water; or that they are diminutive cubes, having six sides and eight angles; as also that these sides have a concavity answering to the convexity of the particles of water surrounding them. Leeuwenhoek observed in the transparent liquor in which the red globules swim, “certain bodies of a quadrangular figure, which he considered to be saline particles” (n. 29). To this evidence may be added, from the same author, the interesting descriptions and delineations (everywhere to be found in his *Epistles*) both of the common salts and others of a fixed nature.

71. If the eight angles above mentioned, and which in their native state in the water cohere and are continuous with the angles of the proximate saline little cube, are broken off, there result so many pyramids, each having four solid angles, and three sides possessing each a like concavity as before. Hence result the *pure acids*, which, when dissolved in fluid menstrua, are capable of exercising such an active force upon other bodies.

72. If common salt, or pure acid, be either broken into

\* The reader is recommended to consult Swedenborg's *Prodromus Principiorum Rerum Naturalium*, Amsterdam, 1721, where he will find a more full description of the generation of the particles of common salt in the interstices of the particles of water, together with figures representing the former particles, their adaptation to the spherules of water, their points of fracture, &c. &c. &c. Swedenborg's views of the composition of the blood-globules will be better understood by a reference to the plates in this *Prodromus*.—(Tr.)

smaller parts, in the foregoing manner, or comminuted by any chemical, natural, or artificial process, we then have quadrangular and triangular solids of a shape similar to the preceding, but smaller or less compounded, and constituting, for the most part, the class of *volatile aërial salts*.

73. If again the particles of these volatile aërial salts be divided into similar parts still more minute, there arise the *most volatile ethereal salts*. Hence the reader may perceive that salts are divisible into three generations, families, degrees, or orders; and that the saline particles, of whatever order, are all similarly cubical or pyramidal; that they are all hard or inert corpuscles, never moveable one among the other without the aid of either aqueous or atmospherical substances; that they are of themselves fixed, and have a tendency to impart a fixedness to other things; that they are neither expansile nor elastic; and that they temper in different manners the fluidity of active substances. But the salts which are of the superior degree, are more universal, less compounded, and more perfect than those which are of the inferior. The conceptions to be formed of them severally must be perfectly distinct, and must be expressed by different words.

74. From salts of the ultimate degree or class, or those first mentioned (n. 70, 71), by means of the interposition of aqueous elements, auras, oils, and spirits, *fixed salts* of every kind are formed; also every kind of *alkaline, acid, and essential salts*, the specific differences of which are without number.

75. From salts of the second degree or class (or those referred to in n. 72), *oils* are produced and conglomerated. These salts constitute the superficies of the parts of the oils, which parts are spherical, the ether occupying their internal cavity. From these again, according as in different manners they coalesce with the fixed salts, arise those *urinous, gross sulphurous, pinguedinous, nitrous-aërial*, and other substances, which are to be found in every vegetable and animal.

76. From the saline elements of the first order or class (or those mentioned in n. 73, which are fluent in the ether), there arise *spirits*, which also consist of spherical particles, whose superficies is occupied by the beforementioned elements, and their interior cavities by ether. These spirits are therefore as it



were most highly rectified oils, or oils forming a class peculiar to themselves. From these are produced numerous *volatile, subtile sulphurous*, and refined *pinguedinous* substances,—each according to its mode of coalition with the other substances with which it is combined.

77. The particles of oils and spirits are of the same dimension and diameter with those of water, for they are composed of the primitive elements of common salts, whence they derive forms having a like magnitude with that of the particles of water. Moreover common salt is the measure and type of the particles of liquid substances; and when these particles are fitted to the hollow sides of the saline particles, and are as it were poured into them, there arises a convexity in the liquid particle answering to the concavity of the saline.

78. From these considerations it is clear, that by help of a perfect chemistry, such as that which is exercised by nature, and which consists in being enabled out of anything to produce anything, we may, out of one compounded salt or a quantity of primitive salts, by help of distillation, sublimation, rectification, circulation, filtration, commixtion, digestion, precipitation, or crystallization, educe any substance or menstruum we please.

79. Such then are the principles on which I have very briefly descanted, of salts, oils, and spirits, so far as I have been able to deduce them from the experimental sciences in general. This doctrine of salts however, considering that it is of such exalted utility, and that it requires for its full development such immense research, demands a still further portion of time and study, in order to be duly understood; indeed it is a subject which merits a separate treatise. Thus much however have we thought it requisite to state concerning the active and passive, the simple and compound substances of the mundane system, or, the auras and salts in their relation to the blood. Let us now proceed to their accidents.

80. *To this we must add a knowledge of the causes of heat, fire, flame, cold.* The real and veritable animal life imparts to the blood a certain kind of heat, which is proper to the blood alone, and is intimately contained in every portion of its structure; but it is there as a bland, benignant influence, gently warming the viscera, and kindling the fires of the little laboratories

which are everywhere scattered through the system, so as to enable them to carry on their operations. According to the emotions of the animal mind, or the vitiated states of the body, this gentle influence grows more intense, till it assumes a degree of fervor, and reduces the viscera to a state of feverish debility. Then again we find it subsiding, and often to such an extent as to superinduce upon the limbs a state of cold shivering. As soon therefore as the blood is drawn from its native veins and living fountains, then, in consequence of the loss of its heat, its life begins to expire, its substance to be converted into clot and sanious matter, and to thicken into a viscid and pultaceous mass. Such is the manner in which that which once was blood, a fluid, and the life of the body, gradually decays. Since therefore the heat above mentioned is both the antecedent and the consequent of the changes which take place in the animal mind and in the body, and since the vital functions possess a vigor according to its degree, it will be of importance to inquire into its cause, if we would find out the nature of the blood. The question therefore presents itself, What is heat, and whence does it arise?

81. What is heat? The rational mind, educing principles out of principiates, knows of heat as no other than a tremulation\* and gyration of the active parts of the body, or of the spirituous fluid, whence arises a firmer coherence, and a quicker and more efficacious force of acting upon the contiguous parts. But again, whence is heat? It proceeds from the contremiscence of the salino-volatile parts both of the first and second order; so that a contremiscence of these parts, in whatever substance it arises, creates also at the same time a similar contremiscence of the auras or spirituous fluid.†

82. For nothing is a more ready excitant of heat than the volatile urinous salts, such as exist in sulphurous, bituminous, resinous, cerous, pinguedinous, oily, spirituous, nitrous substances; also in vegetables, and in the meteoric substances of the atmosphere. Again, nothing is more calculated to promote

\* Tremiscentia.

† Unde est? Acceptum ferri contremiscentiæ partium salino-volatilium tam primi quam secundi ordinis; quare est causa, quodcunque illa, et cum illis auras aut fluidum spirituosum contremiscere facit.



it, than the auras, and the spirituous fluid which emulates their nature. Consequently nothing excites it more easily than the blood, in which reside the volatile urinous salts or sulphurous substances already mentioned, as also the spirituous fluid, which is in a state of intimate union with the blood. Genuine heat therefore increases with the quantity of spirituous fluid, and of the volatile salts adjoined to the spirituous fluid, as we find to be the case in the season of youth; it decreases again with the decreasing quantity of these substances, as in the case of old age; it varies according to the various states of the blood, produced by a variety of causes; it is perpetuated by means of the continual resolution and coalition of the parts of the blood, as when it circulates from the arteries through the veins, capillary tubes and fibres; as well as by the continual exercise of the blood caused by the brains: thus the heart and the brain by their united operations vivify the heat. "If the powder of dried crassamentum," says Gulielminus, "be thrown into the flame of a candle, it instantly catches fire like resin, and explodes with a noise and crackling, which is the effect of salts; giving rise to the inference that sulphur is present in the watery portion of the blood, and this, in a very subtile and volatile form. . . . The blood of young persons is hotter than that of the old. . . . The blood of old persons is more vapid, &c." (n. 32, *ad fin.*)

83. As the successive generation of salts is threefold, so also the efficient cause of heat in the blood, and the heat itself thence derived, are of a threefold origin, degree, and nature. For 1. There is an extremely mild heat, which the volatile ethereal salts produce interiorly in the plano-oval spherules. 2. There is a stronger heat which is proper to youth, which is also sensible to the feeling (or touch), and which the insinuated urinous aërial salts produce in proportion as they excite the spherules in general. 3. Lastly, there is an immoderate febrile heat, which takes place when any integral part of the blood, or any volume of its parts, from some cause, generally external, is thrown into a tremulous and hurried motion, more impetuous than is natural. 4. Within these three degrees of heat lies concealed, as their internal principle, the activity which is proper to the animal spirits, which is not heat such as that of which the external senses are cognizant, but which is the life or origin

of heat; or rather, an attribute of life, and a force which is a necessary adjunct of animal nature. Consequently the seeds of heat are inwardly latent in the activity of life.

But in what manner these seminal principles, distinctly one from the other, reside within and actuate the individual parts of the blood, cannot be comprehended, unless it be first shewn in what manner the spirituous fluid, the plano-oval spherules, the volatile ethereal salts, as well as the aërial and fixed salts, occupy their proper and appointed place in any globule of blood.

84. That *fire*, glowing and luminous, arises from the disengagement of the parts of the auras, and from the excitation of the parts thus liberated into their natural gyration; and that *flame* is the smoke or soot which consists of so many as it were molecular burning coals, or that it consists of small volant ignited particles, can be shewn to ocular demonstration by experiment: and as the knowledge of one opposite may be derived from the knowledge of the other, we may hence deduce the nature of *cold*. It may thus be seen that nothing real exists in heat, fire, flame, or cold, since they are only the affections and qualities of trembling and gyrating substances, or on the contrary, of such as are quiescent.

85. *And colors, together with all the other subjects of experimental chemistry and physics.* For natural blood distinguishes itself from its circumfluous serum by its redness, and this to a greater degree in the arteries than in the veins. This distinction is of one kind while the blood is poured into the lungs from the right side of the heart; of another, when, after meeting the air, it is returning to the left side of the heart; of another, when it distributes itself by the internal carotid and vertebral arteries, after receiving the purer vapors supplied within its kingdom; of another, as it is dropping from the glands of the liver into the gall-bladder: in a sucking infant it differs from the distinction observable in adolescence; in adolescence it differs from the one observable in manhood; and so on through the states of old age and final decrepitude; for the blood, as it successively passes through the various ages of life, so it successively declines from a vigorous to a vapid state. The distinction is also different in different states of sickness, whether of body or of mind; as when the blood is colored with bile, or grows crude in conse-



quence of the chyle not being duly prepared and vivified; in which case it becomes of a dark color, or a brown, or a pale red,\* or a light green. When drawn into a basin, it distinguishes itself not only by its color, but by its gravity; the florid blood occupying the place immediately under the serum, the lowest part sometimes assuming a disagreeable blackness. Moreover when blood, divided into its particles or plano-oval spherules, is inspected through a microscope, it exhibits scarcely a shade of its proper color; and yet when a number of the particles are conglomerated, it assumes a hue of deep red. Since therefore the blood so remarkably distinguishes itself from the other liquids of the body by its various colors, it is of importance to the knowledge of the blood that we ascertain what color is, and whence it originates.

86. Color, then, as we learn from phenomena, is a certain discrimination of light and shade, and a certain determinate ratio and analogy thence arising in those extremely minute objects which do not come distinctly within the visual perception. For in objects of this kind, the eye cannot discern between luminous and shady rays; wherefore it apprehends only the general image of the discriminations and differences, as represented under the beautiful appearance of colors. White and black are two opposites, as light and shade, the modifications of which are the intermediate colors. This is confirmed by the transmission of the solar beam through spheres of glass, bubbles and watery vapors; also by its inflection and resilience; by prisms placed in different positions; by the appearance of colors in spaces where the shade perceptibly begins to discriminate itself from light; by various chemical mixtures and precipitations; by the beautifully colored objects of the vegetable kingdom in general; and by numberless other phenomena. From all which particulars severally illustrated, it may be clearly shewn, that in color there is nothing which is real, but that it is solely an illumination which is produced by the sun, by candle-light, fire-light, and so forth, variegated according to the various constitution\* of the bodies interposed, particularly such as are transparent. With an attention to these principles, and after an

\* Helvi.

† Temperationem.

ardent pursuit of this class of optical experiments, I have seemed to myself to have attained to the ratios of shades and lights by which single colors might be respectively designated, and in some manner also to the forms of the parts trajected by the beams.

87. It is well known, that nothing produces with greater distinctness and nicety the different ratios and forms of shaded light, than the volatile, urinous, alkaline, and sulphurous salts, as so many triangular, prismatic, and quadrangular corpuscles ; which, when they dispose themselves throughout any compages in an orderly arrangement, give rise to a general modification of color, either red, green, or yellow ; and hence results the pictorial or scenic effect which is distinguished and comprehensible only by a general visual perception.

88. This is more particularly true in the case of the blood, between the compages of whose parts interpose the volatile salts, from which the red color receives all its modifications ; a color which is heightened and vivified in proportion to the interposition of similar minute particles in the less compounded blood, or in the spirituous fluid ; which is enriched in proportion to their quantity ; and is obscured in proportion as the congeries is disarranged by the intermixture of heterogeneous and opaque substances that confound the discriminations of light and shade. The color, however, is different whenever the ratio of light in a spherule is less, for in this case it assumes a green or azure tint ; if the ratio is greater, the tint is yellow, and thus the transition is effected from black to white by successive gradations ; a transition which takes place when all the volatile saline particles become translucent, or reflect the rays inordinately, as is the case with irregular fragments of ice or of glass.

89. But before we endeavor to ascertain in what manner the saline triangular particles or trigons, both of the aërial and ethereal order, reside in the blood, or are fitted into its parts, let us suggest some reason, (an obscure one though it be, and bordering upon conjecture,) for this modificatory variation existing in the blood : this reason is, that colors result principally from salts of the second order, such as the urinous, the grosser sulphurous, the nitrous-aërial, and the essential oils of every



kind in their free state. From the most volatile ethereal salts, however, color does not arise, these rather serving to insinuate the first principles of color, and to impart a strength and brilliancy to objects. The plano-oval particles, says Leeuwenhoek, as quoted by Gulielminus, “are colorless, or quite transparent. If, however, a number of them be placed one upon another, they exhibit a reddish tinge” (n. 32). For when they are in a state of mutual conjunction, immediately urinous or volatile salts of the second order interpose themselves. Whence Boerhaave observes, that the globules of blood, “when divided into their component parts, present the appearance of a pellucid yellowish serum of various shades” (n. 31).

90. *Nor is this sufficient, since the science of the blood extends also into the fields of physiology and of pneumatology, or the function of the animal spirits.* Thus the animal mind is affected the moment the blood suffers, and the blood is affected the moment the animal mind suffers, as we find to be the case in mania, melancholy, phrenitis, fever; also in states of anger, hatred, envy, sorrow, joy, cupidities of various kinds, &c.; also in various temperaments, &c. So that animal nature would seem to have fixed her place of abode in the blood, or designed to open an inward communication through the blood to the shrine of the rational mind; as we may see illustrated in the case of brutes, or animals destitute of intellect, since it is evident that they are led by their instincts to ends which emulate even those of a rational nature, according to the variously altered and incited states of the blood. The reason of this is, that the continuity of the fluxion of the liquids of the body is such as is the continuity of the extension of the solids, or parts that cohere, the beginning or end of which continuous chain we in vain seek in any assignable first or last limit, since it is a perpetual circle or infinite spiral.

91. *From an attentive consideration of these things it may in some measure be evident, that the spirituous fluid constitutes the essence of the life and activity proper to the blood.* See n. 37, 38, 39, 40, 41. *From which spirituous fluid there exists, through the medium of a copious volatile substance derived from the ether, a pellucid or middle blood.* See n. 53, 54, 55, 56, 57. *Lastly, through the medium of fixed and urinous salts employed in tem-*

*pering, copulating, determining, and finally, perfecting the composition, there emerges the red and heavy blood.* See n. 43, 44, 45, 47, 48, 49, 50. This is the genetic definition of the parts of the blood, to which may here be added n. 46. For the salts which are of a triangular and octangular figure, bounded in a variety of ways, being of an irregular shape, as remote as possible from the spherical, and of themselves most unadapted to any kind of motion, *temper* the intense activity of the spirituous fluid, (which observes only the most perfect form of motion,) in order to endow the blood with a certain consistence. Again, that all the parts of the blood may be held together in that connection to which nature is constantly aspiring, the salts *copulate* them. They also *determine* the limits proper to the form of the parts. Lastly, that the blood may possess within itself everything of which the animal is in need, the fixed and urinous salts *perfect* its constitution.

92. *Into these original principles this latter kind of blood suffers itself to be divided according to degrees during its progress through corresponding vessels, or those first of a like order with itself, then through the capillary tubes, and lastly through the fibres.* As we may see in Chapter II. of the present Part, on the Arteries and Veins, and in Parts II. III. IV. V. and VI., on the Brain. Hence it follows that in the composition of the blood we have to take into consideration three degrees, which indeed are perceivable distinctly one from the other, inasmuch as the blood is compounded of each distinctly, and into each is distinctly divided. A globule of blood whose parts are held in connection by so many triangular and quadrangular saline particles, is hence shut in as it were by such numerous barriers as to appear placed out of the reach of all investigation. We only fall into needless perplexities, and make difficulties where there are none, if we know not how to subordinate one thing to another before we coördinate them respectively. That the globule above mentioned is of a threefold origin, order, nature, and hence dimension, is a fact that emerges from a laborious and wide investigation,—a fact which hitherto nature seems to have utterly concealed. If therefore we would lay open the nature of the globule, we must conceive, that the spirituous fluid constitutes the *first* order; that the less compounded blood, or



the fluid consisting of plano-oval spherules, constitutes the *second* order; and lastly, that the red blood constitutes the *third* order; which last thus enjoys in a manner a triple maternity, and is the great great grandson of the spirituous fluid.\*

Now to the end that these three families may combine, there is need of saline elements of a threefold order, to temper, copulate, determine, and perfect the fluids; namely, 1st. Subtile ethereal sulphureo-saline elements, which may affect the spirituous fluid. 2nd. Aërial elements which may affect the less compounded blood. 3rd. Fixed elements that may affect the red blood, which thus becomes as it were thrice born. That it is out of this number and order of elements that the several parts of the blood are from the first united together, the reader may see confirmed in Chapter III. of the present Part, on the Rudiments of the Heart. That all the parts of the blood are thus conjoined into one in the most intimate manner, the reader will see explained in Chapter VIII., on the Philosophy of Degrees, and also in n. 96. That moreover at every gyre of the circulation, while the blood is passing from the blood-vessels into the bloodless capillaries, and thence into the beginnings of the nervous fibres, it is again separated into fluids of the like degrees, or else divorced from the system, the reader may see confirmed in Chapter II. of this Part, on the Arteries and Veins.

93. Thus will it appear that nothing is more incident to the blood than to be resolved and compounded, to die and to revive, thus to be perpetually renewing the very same disport of nature which it commenced from its first rudimentary state. When the blood however in the course of its circulation has thus been analyzed into its first principle, it does not perish, but continues its life in the purest substances of its nature, which enter into and traverse the fibres; all the earthy and saline inert atoms being deposited at the mouths of the channels where the division begins. Thus the blood does but return to its parent spirit, renew its birth from its first principles, and descend again into the system.

\* Qui ultimus sic quasi trimatris est, & fluidi spirituosus trinepos.

94. If we thus triplicate a globule of blood, the rational mind will then recognize in it the truths of the theorems and axioms of its philosophy ; namely, that the cause is present in the thing caused, the simple in its compound, the efficient in its effect, and the universal in the particular ; nay more, that the whole is a subordination of causes, the intermediates\* of which are the effects of the superior cause, and the efficient causes of the inferior. For the spirituous fluid is the determining cause of the less compounded blood, and this latter of the red or grosser blood ; consequently the less compounded or the intermediate blood is the effect of the spirituous fluid, and the efficient cause of the red blood. In blood composed according to these gradations, will be found to have concurred many other laws belonging to the same philosophy ; such as, that subsistence is perpetual existence, and that the essential determinations of things coexistent are successive, &c. Further information on this subject will present itself to us as we proceed.

95. *Blood in the last of these three degrees ought to consist, for the most part, of six plano-oval spherules, which fit themselves into so many hollow sides of a single particle of fixed salt. Whence arises the spherical figure of the whole.* That the individual parts of the blood are globular or spherical, is confirmed by the universal testimony of those who have examined them. That every globule consists of six lesser ones, is indeed denied by Lancisi (n. 30), but asserted by others, and among them by Leeuwenhoek, who “clearly discerned, as he says, that every globule was compounded of six smaller ones. . . . He subjected the larger globules to violent motion, when they burst in pieces, and displayed the smaller globules” (n. 29). I am inclined to think therefore that the fact is not so much denied by Lancisi as unobserved.

96. The foregoing particulars, as established by personal observation, being premised, we now proceed to the construction of the sanguineous particle. 1st. Let there be given a most spirituous fluid, the nature of which we shall investigate in our remarks on the brain. 2nd. Let the extreme volatility of this fluid be tempered by ethereal elements (n. 53, 92), and to speak by analogy, let these two be as it were amalgamated in such a manner as to leave remaining both the fluidity and the tendency



to a perfectly spherical form ; for the volatile ethereal salt, when mixed with the most fluid substance of nature, does not destroy, but only subdue or subordinate its forces. 3rd. In this manner is constituted the blood next in degree, or the less compounded blood. 4th. Let the spherules of this fluid be fitted each respectively into the six hollow sides of a single particle of common salt (n. 70, 77), which may serve as a basis, fulcrum, and mould of the whole. 5th. At all the eight angles, where the spherules do not mutually touch each other, let there be inserted the urinous or volatile, and sulphurous aërial salts (n. 72), which are of the second order, and which are small cubes and solid triangles, by the interposition of which, the whole compages is strengthened. 6th. Hence will be found to result the entire spherical figure of the compound particle, or sanguineous globule, which is voluble, fluid, flexible, possessing the power of adapting itself to any contractedness of passage, soluble, exhaling warmth, red, heavy, holding together all its parts so as to seem to combine them spontaneously into one, and in the most orderly arrangement, while within them reigns that spirituous and vital substance which is the only substance of its kind.

97. *But although the spirituous substance of every animal enters into all the genuine blood of the animal as its principal and only vital substance, nevertheless in every species of animal the blood is different.* That the blood is different in every species, which lives on a different food, and which nourishes its own blood by a different kind of substance ; nay, that in some species, as in aquatic animals and insects, it is white, yellowish, cold, having its parts of an oval form, natural history constrains us to admit. When chemically examined it does not supply a like quantity and quality of phlegm, oil, spirit, and earth, nor when dissolved in menstrua does it manifest the same alterations. When viewed in itself, it does not exhibit a similar redness, warmth, fluidity, gravity, or coalescence into filamentary substance. The cause or the reason for which the blood is different in every species of animal, is to be derived from the very fountain of the blood itself, or from its spirituous fluid as its principal substance, as the only one of its kind, and as having a nature proper to each different genus (n. 48).

98. *And varies in the individual subjects of every species,*

*according to temperaments, states, and ages.* The questions for examination, therefore, are, what are the generical variations which blood so compounded can undergo. Namely, what are its variations in relation to, 1st. The quantity and quality both of its own serum and of that which is circumfused. 2nd. The quantity and quality of the spirituous fluid, and the less compounded blood thence arising in the red globules. 3rd. The quantity and quality of the volatile and fixed salts which enter into the construction of its parts. 4th. Its state proper to every mental and bodily suffering, and its common or general state while flowing in consort with its associate substances. 5th. The series of diversities in each of the foregoing variations, as contained within its two extremes in regard to greater or less; and again, the series of diversities in each of the foregoing variations, where the causes of the variations concur. 6th. The specific and particular changes which arise in consequence. The prosecution however of all these enquiries, is a work of immense labor, and extends through the whole pathology of body and mind.

99. From the foregoing questions I shall select only one for more particular examination; namely, the one which refers to the variations of the blood in respect to the quantity and quality of the volatile and fixed salts which enter into the construction of its parts. 1st. Blood of the second order, or the less compounded blood, may possess too great a quantity of volatile saline ethereal particles, or may be full of heterogeneous vitiating substances, and consequently may have an undue tendency to fixedness, sluggishness, and torpidity; or on the other hand, the opposite may take place. 2nd. The red blood, or blood of the third order, may possess, interposed between its particles, a too great quantity of urinous salts, and of other and heterogeneous substances affixed to those salts; it may even become adulterated by pure saline acids (n. 71), and may thus have a tendency to hardness, and to become more acrid and heavy; for when substances of the third order join themselves to substances of the first without the intermediates of the second order, the harmony between the degrees is destroyed. 3rd. The blood, instead of being cemented by a cube of common salt, may possess, interposed between its particles,



merely solid triangles connected one with the other, such as nitrous earthy substances carry with them;\* these saline corpuscles may thus be surrounded not by six, but by five plano-oval spherules; hence the blood may have a tendency to grow acid, pale, cold, and may consequently be endued with a different nature, as it certainly is with a different appearance. 4th. The blood may be beset with particles of oil, spirit, or water, instead of being surrounded with its plano-oval spherules, for all these particles are of the same diameter (n. 77); and thus it may be rendered spurious, and as such be discarded into the gall-bladder. Not to mention other causes of its adulteration: from all which it follows, that *there is both legitimate and spurious blood according to the health of the body*; in conformity with what is stated by Leeuwenhoek, who observed that when he “was ill, the globules of the blood he drew from himself appeared to be harder and firmer; but when he was in a good state of health, they were better connected with each other, being softer and more fluid: whence he infers, that death may sometimes proceed from the hardness of these globules” (n. 29).

100. *With respect to the first substance of the blood, or the spirituous fluid, and with respect to its other substance, or the purer blood, it is to be observed, that each in its own degree is most highly elastic, most highly susceptible of consociation, plication, as well as of reduction into every form. But into whatever form it is reduced, it naturally aspires to its most perfect form, and is in the effort to return to it.* On this subject Leeuwenhoek says, that he observed, “that every globule was compounded of six smaller ones, which were as flexile and soft as the larger. That in proportion as the larger were stretched out or elongated, the smaller assumed the same lengthened figure, till they became like threads. . . . That they [the globules] passed by and into one another, and by reason of their softness could be moulded into various shapes, but when at liberty immediately recovered their former globular condition” (n. 29). Now, what is this but elasticity, growing up in the family of constituent particles? For this phenomenon would seem assuredly to indicate, that unless these fluid substances were under

\* See the Theory of Nitre in the *Prodromus Principiorum*, p. 90—120.—(Tr.)

the restraint imposed upon them by the volatile salts, or by the inertness of passive bodies, they would exhibit a degree of elasticity and volatility surpassing every conceivable mode. I am in doubt as to what principle or what experimental fact they rest upon who would predicate hardness of these bodies in their natural condition, when we find that they decline from their active life into an inactive and moribund state in proportion as they decline from their elasticity. I know not what universal substance could enter into the blood and compose it, if in its least parts it were of itself inert, incapable of adapting itself to the various little channels and pores of the body ; and if it were at any, even the smallest, moment of time, during the period of its circulation, to lose any considerable portion of its forces, or at any single point to stand still or offer resistance.

If however the principal substance of the blood experiences no loss of the force it has once received, (according to the universal law of pure elastic fluids,) but communicates the whole of the force impressed upon it both to contiguous and remoter distances ; or if it impresses the remoter regions in the same degree as the parts which are nearest, then we are enabled to comprehend how the nature of a part is transferred into a volume, how the nature of the whole volume returns to that of a part, and how all things are enabled to conspire to produce one effect, belonging to one and the same end. Besides this law to which I have now adverted, I may observe that all the other laws of elasticity coincide with the powers which are ascribed to the spirits, the nervous juice, and the blood. That they must be thus ascribed, experimental fact demands, and this, in the same proportion in which life consists with their faculty of yielding, and death, with the loss of that faculty, or with their hardness.

101. The most convenient form in which any force of nature can act, is the spherical ; a form which deserves to be called the genuine form of activity and motion, for it is one that has no angles or prominences, which are the sole impediments to motion. It is also the first principle of all the other forms, as well as their basis and measure ; while again the first principle of the spherical form is the perpetually spherical or cubico-spiral, in which the substances, while in their state of utmost



activity, describe an ellipsis distinguished by its poles and greater or lesser circles, according to the irrefragable laws of geometry. It is into this higher curve that nature betakes herself, as she recedes from her posterior world into her prior ; and hence we may presume, that Leeuwenhoek was following no hallucination when he designated the spherules of the blood as plano-oval (n. 32). *Thus the purer blood and its spirituous fluid are endowed with such perfect fluidity, and are so capable of acting according to every mode of an efficient cause, that in these respects nothing can surpass them.*

102. *In the last or ultimate composition, which is the blood properly so called, exist the same qualities, but more imperfectly in accordance with the degree of composition.* On this subject, Leeuwenhoek states, among the records of his experiments, that he “saw that the globules were flexible and pliant in proportion as the blood was healthy, and in passing through the small capillary arteries and veins, changed to an oblong figure . . . three times as long as broad. . . . In a tadpole, the particles of blood were flat and oval, and . . . sometimes, by reason of the tenuity of an artery, they were made to assume a tapering figure” (n. 29). For the order according to which they increase by composition, is the same according to which they decrease in elasticity, in the exercise of vital powers, or in the perfection of each individual quality ; or, in other words, exist as substances less fluid, less pliable, less divisible, less constant, and less similar to each other, &c. The ratio of these qualities is to be found in the multiplication of the primitives in the derivatives, and in the consequent augmentation of gravity, inertia and resistibility.

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103. Thus far I have proceeded analytically, or by help of experiment and reason attained to certain simple principles. I now propose to change the order of investigation and to proceed synthetically ; and by assuming as facts the causes which have been traced out analytically, and availing myself of others in addition, to explain the various phenomena which occur in respect to the blood. First then we explain,

104. *What is the quality of a volume of the blood as contained within its vessels.* We may observe in general, that by a volume of the blood is meant a volume of the parts which are in a state of volution or fluxion, of whatever order the blood may be. A *pure volume* exists, when the parts are all of one and the same order, as in the case of the red blood, or the more uncompounded blood, or the spirituous fluid, or water, air, ether, &c., each considered separately. A *mixed homogeneous volume* exists, when there is an interfluence of other parts, which nevertheless are of the same order with that of the blood; as when salts, oils, or aqueous substances are flowing with the red blood; or urinous, sulphurous, volatile, aërial salts with the less compounded blood; or the ethers with the spirituous fluid. A *mixed heterogeneous volume* exists, when there is an interfluence in the blood of other parts of a different order; as when red blood is carrying with it urinous salts, etherial elements, and so forth.

105. That a mixed heterogeneous volume exists particularly in the veins and in the heart, nay, and even in the larger arteries; but that before it reaches the capillary vessels, it changes into a mixed homogeneous volume, and at last into a pure volume; and that the volumes belonging to every order require also vessels of a corresponding order, or corresponding ways of determination, will be shewn in our observations on the Glands. One common rule (of which we shall speak in Chapter VIII.) for knowing the quality of any volume contained within its vessels, is this, that every individual particle of a pure volume is the smallest volume belonging to that fluid, no smaller volume being assignable in that degree; that the same part represents a larger volume, nay more, the largest; and that the one is to the other as a unit to a number or aggregation of units. This rule also holds good with regard not only to the blood but to the auras, aqueous elements, oils, &c. Thus from a given particle we may learn the nature of the volume, and from a given volume the nature of any one of its particles.

106. *What is the quality of the crassamentum?* It is the intermediate between the volume of the fluid and the mass of the solid. For as the fluid changes into the solid, it ceases to be fluent and begins to be consolidated. The fluid is then in a



state intermediate between the two, when it begins to be soft, sluggish, and thickened, whence arises the crassamentum, clot,\* and concretible serum. Such as are the volumes, such are the crassamenta belonging to the volumes, and such also are the masses; that is to say, if the volumes are pure, mixed homogeneous, or mixed heterogeneous, such respectively are the crassamenta and the masses.

The crassamentum is the ulterior degree or the fourth composition of the blood, which exists in consequence of the interposition of fixed salts, aqueous substances and oils, derived from its concomitant serum, when it passes out of its native vein into an atmosphere not its own. A similar change is experienced within the vessels, when the volume cannot be purified by its regular circulations, and this, for any of the following reasons: because there is an obstruction in the smallest vessels; because by means of the stomach, lungs, or external cuticle of the body, aliments are received into the system, which are in a crude or unsuitable state; because the aëreal substances enclosed in the aliments are not ejected by the pulmonary vesicles; because the liver does not absorb the spurious blood, or pour out its biliary fæces in sufficient quantity; because the kidneys do not excrete the serum thrown into them; because the native warmth of the system declines; because some inordinate febrile heat has seized upon the system: not to mention other causes of a similar nature, all of which rapidly change the blood from its natural condition into the one it assumes in a state of extravasation. Hence we may learn,

107. *What and whence is the sanguineous fibre?* On this subject Malpighi says: “If we take coagulated blood, . . . and cut it into longitudinal slices, and then repeatedly wash it, we shall observe on its upper part a crust of pellicle composed of whitish channels, and almost pervious with vesicles, which are filled with a transparent juice of a less specific gravity than itself; and if we trace the production of this substance still farther, just where the coagulated mass of blood begins to redden, we shall find it elongated downwards, and divided into a fringe work of little fibres, creating by their beautiful impli-

\* Grumus.

cations little winding channels and sinuses, which are distended and tinted by the red atoms they enclose; and we shall moreover observe a yellowish serum confined in some of the larger spaces, or confounded with the red ichor (n. 33). And Gulielminus observes that Bohn, “on a very close examination of fluid and warm blood, found in it no appearance of fibril or filament;” but adds, “we take it as certain . . . that the crassamentum of blood consists of reticulated fibres, between which are loculi, porosities, areolæ, or interstices, in which both the serum of the blood and its red globules are contained,” &c. (n. 32). The sanguineous fibre, therefore, arises from the circumstance of the parts of any volume coalescing into one larger and compounded part by the insertion between them of little solid saline triangles, or tesserae of salt, which fit together in every diversity of manner. For the sinuses or depressions on the sides of the salts correspond exactly to the convexities of the plano-oval spherules, oils, spirits, and aqueous substances (n. 77). Whence there follows an easy and almost spontaneous coition, presenting a fibrous, lamellar, reticulated, arborescent concretion of the parts. But the fibres, little clots, and small portions of crassamentum in the sanguineous volume, are so many signs of its unnatural constitution.

107½. *Whence arises the gelatinous crust?* The gelatinous crust arises from the circumstance of the sluggish serum of the blood, enclosed in the crassamentum, escaping in small quantities and condensing on the surface; a circumstance which happens, when there is a less quantity of water in the blood, and a greater of a thick oil in accompaniment with the fixed salts; or when the quantity of each is equal, but that of the alkaline salt which unites the water and the oil is larger. Whence a cutiform coagulation proceeds. “It sometimes happens,” says Gulielminus, “that the upper part of the clot has no appearance of redness, but turns into a yellowish gelatinous substance, while the lower part is of the foulest hue” (n. 32). And Malpighi alludes to “coagulated blood, with a large and thick white crust, that is not distended with concretible serum, but forms a kind of coat, soft and pliant,” &c. (n. 33).

108. *Whence arise the phlegm, oil, spirits, and earth, together with many other things, elicited by distillation?* In answer



to this question, we may observe, that these substances never previously existed in the blood under the form in which they are elicited, but having undergone a chemical metamorphosis by being submitted to the action of fire, emerge with an altered appearance, and as a different denomination of substance. Thus fat never secretes itself in the vessels in the same form in which it exists in the cellular substance, neither do milk, saliva, nor any of the other animal liquors. In like manner neither do the most fragrant fluids and essential juices of flowers, leguminous plants, and fruit trees, exist under this form in the earth, but are elicited out of their respective substances; for art and nature out of simple substances make compounds, and out of compounds educe simple substances. This composition and resolution take place more particularly in the animal kingdom, where nature is seen operating in all the perfection of art and science, procreating every single thing which may be rendered conducive either to particular or general use.

109. Blood when submitted to distillation, in the first place disunites its several parts one from the other, and ejects its aqueous substances and connecting saline particles; whence arises the *phlegm*. Of the parts which are set free, all the salts of the second order, or as they are called from their compounds, all the urinous, sulphurous, volatile ærial salts that beset or reside within the blood, it disengages and dispels, by which means the compages of the parts is laid open; whence arises first the thick and dark *oil*, then the more attenuated and yellow oil. At length it sublimates from the mass the residuary saline corpuscles of the same order with itself, together with the plano-oval spherules and their lightest ethereal elements; whence arise the *spirits*, these all existing under the form of vapors, under which form also exist the oil and spirits. Lastly, there remains the common salt, the basis and fulcrum of the whole, together with the other more fixed salts, which from the want of water did not previously suffer themselves to be exhaled; whence originates the *earthy substance*, from which, as we find upon experiment, a small quantity of common salt may be extracted. Thus by the chemical application of heat are the interior recesses of the sanguineous parts laid open, and this, in succession, according to the degrees of their composition. Nor would it be diffi-

cult to assign the proportion of each constituent, if the same quality or character of blood everywhere obtained.

110. *What are the essences, menstrea, and other recondite substances, which can be elicited by other modes of operation?* Let us here make mention only of that most spirituous essence, which perhaps might be elicited out of the volatile ethereal substances of the purer blood. For since the blood carries interiorly, and in no very close connection, the primitive entities or initiaments of all the salts, oils, and spirits, it follows that by help of some recondite process of cohobation, there might be prepared from it alone a certain alcahest or sublimer quintessence. But since no substance of bladder or glass, no lining or sealing, could prevent elements so subtile from flying off in whatever direction the ether might convey them, there is no prospect of our extracting such a spirit, unless we knew how to imitate the art of animal nature, in long and cautiously regulating the degrees of heat from the lower upwards through all the superior degrees, and thus alcoholizing the spirit once extracted. *Sed hoc opus, hic labor.*

111. *What are the changes produced by the addition of salts and aqueous substances of different kinds?* By the addition of salts or liquefying substances, the blood is coagulated, resolved, or else remains unchanged. When one part is *coagulated* with another part, or extrinsically, it thickens, grows hard, and acquires more fixedness. This state arises from the blood itself on the cessation of its heat and motion; or from causes foreign to the blood, as when binding substances are introduced between its parts. When the part of any part coagulates with the part of some other part, or intrinsically, it changes color, grows turbid, black, and heavy; assumes a firm consistence, and becomes indurated by the injection and circumfusion of elements of the second order. When a part is *resolved* or set free from a part, or extrinsically, it becomes liquid, and of a cold temperature, and retains its purple color, the bonds of connection being absorbed or disrupted. When the part of a part is set free from the part of any other part, or intrinsically, it grows soft, viscid, yellow, shining, and at first grows warm; it emits a varying odor, the elements which bound the parts together being extracted or discharged. When the blood *remains unchanged*, it exhibits no phe-



nomena either of coagulation or solution, as in cases in which those elements, which long habit, affinity, and relationship had previously familiarized, associate themselves with the blood; as in the case of elements which contain its essential seminal principles, and which Malpighi enumerates, namely, nitre, aqua vitæ, common salt, rock salt, sal ammoniac, sulphur and harts-horn, which color it with a beautiful crimson, and for a short time impede the coagulation of the blood (n. 33), that is to say, repair its loss. The process however by which those menstrua, whether dry or liquid, coagulate the blood or dissolve it, must continue to remain among the secrets of nature, so long at least as we continue entirely ignorant of the composition of the adjuncts of the blood.

112. *What are the changes which the blood undergoes when shaken and cocted?* When the water is holding in separation one part from another, then the constipation, coagulation, and resolution of the parts of the blood are impeded. What are the changes produced when the blood is *roasted*? The aqueous substances being in this case expelled, the inward living heat ceasing, and the external heat consuming the mass, the several particles combine in a confused disorderly manner, giving rise to a dusky and black coagulum.

113. *Whence arises the frothy turgescence of the blood when placed under an exhausted receiver?* “If blood be placed under the receiver [of an air-pump],” says Lancisi, “not only has Boyle, but we ourselves have often observed it emit bubbles, and almost effervesce. . . . Leeuwenhoek asserts . . . that no air can be obtained from fresh venous blood, but only from that which has for some hours been exposed to the atmosphere” (n. 30). And Gulielminus observes that, “Those who have noticed extravasated blood, have not perceived in it anything analogous to air. . . . Nevertheless, when in contact with air, blood, whether arterial or venous, changes its color” (n. 32). The phenomenon of air escaping from the blood is therefore accounted for in the following manner: while blood is issuing from an open vein, it is imbued, during its transition into the basin, and even in the basin itself, with no small portion of atmospheric substance. Moreover, the chyle not unfrequently carries its glomerated particles, within which air had been en-

closed, even beyond the lungs into the vessels themselves. Not to mention innumerable vesicles, through the medium of which elements derived from the ether are insinuated in the veins into the plano-oval spherules, as will be confirmed in the sequel. Now all these aërial particles, when the blood is placed in an air-pump, become distended, and expand into bubbles a portion of the sanguineous mass.

114. *Whence arises its gravity?* A sanguineous globule is as it were a merely saline body, for the spirituous fluid only fills the little sinuses and hollows of its saline parts, of whatever degree they may be, and the quantity of which depends upon the age, &c., of the individual. In the salts there is gravity, in the spirituous fluid levity, or a most active force corresponding with gravity. Whence the sanguineous globule, if the blood be at rest, falls to the bottom of the serum.

115. *Lastly, there is not in the whole compass of nature a single compound entity more simple and perfect than a globule of blood.* Blood comprehends in every one of its spherules, mere first principles, elements, and simples. Consequently it possesses potentially and virtually every single thing in the mundane system which is producible from first principles, elements or simples; that is, everything which is possible. Those volatile ethereal substances which temper the spirituous fluid, are the first and only entities of their own and the following degrees; hence also they are the elements of those degrees. The volatile aërial substances are also the simples of their own and the next following degree; while the saline cube, which is the cement of the whole part, is the simple of its own degree. Although however it be a simple in respect to the coördinate and aggregate substances of its own degree, it is nevertheless, both in itself and in relation to the substances of the superior and prior degrees, highly compound. For there are degrees of simplicity, as there are of universality and priority. The sanguineous globule then encloses within itself the first and least elements, and the determined units of every degree; these elements moreover are so subordinated and coördinated, that each globule of blood can be laid open by distinct gradations according to its distinct elements; for at every gyre of the circulation it is actually thus opened, in order that this process may become a habit, and that



this habit may be preserved ; thus it is capable of producing everything which can possibly exist from first principles. Hence the infinite variety of liquids and solids in the animal kingdom, which proceed from one only fountain, which is the blood. Hence also there is not a single compound entity in the whole compass of nature, which is at once more simple and perfect than the sanguineous globule. *Q. e. d.*

## CHAPTER II.

### THE ARTERIES AND VEINS, THEIR TUNICS, AND THE CIRCULATION OF THE BLOOD.

116. VERHEYEN. "The tunics of the larger arteries are four in number; but the parietes of the minute branches are so thin that they appear to be composed rather of a single tunic than of four. . . . The external tunic of the arteries . . . has nervous twigs ramifying and winding over it in different directions, and is covered by an extremely dense and as it were retiform texture of vessels of every description, but the chief of which are blood-vessels; as is best shewn in the bodies of those who have recently died without loss of blood. To this retiform or vascular tunic succeeds a second, which is properly termed the glandular tunic, because it is beset throughout by minute whitish glands. This second tunic is very thick, and may be readily separated into several layers, and exhibits also in the larger arterial trunks a number of small vessels. The third tunic, reckoning from without, is muscular or fibrous, consisting of annular fibres set thickly together. These fleshy and motive fibres surrounding the arterial tube, are not disposed in a thin and single series, as in the venous coat, but aggregated and superimposed one upon another, so as to constitute a membrane of considerable thickness. The fourth and internal tunic is the thinnest, and is almost entirely membranous, or if you prefer the term, nervous. Its fibrillæ extending longitudinally, cut the annular fibres of the preceding tunic at right angles. In the neighborhood of the heart these fibres are thicker and as it were fleshy. . . .

"The tunics of the veins are almost of the same structure with those of the arteries, but thinner, and arranged in a different order. Thus the membranous tunic, formed of various fibres running lengthwise, is the first; but its fibres do not lie parallel, as in the fourth arterial tunic, but often intersect each other. The second tunic is



vascular, like the first tunic of the artery. The third is glandular, like the second of the artery. The fourth and inmost tunic, like the third tunic of the artery, consists of annular fibres, but thinner, and arranged in a very simple series. . . .

“The vena portæ has thicker coats, so as to appear in a measure to be an intermediate between the other veins and the arteries. . . .

“The veins are much larger and more capacious than the arteries. . . . Nevertheless a much greater quantity of blood flows through the arteries than through the veins, if you except that part of the vena cava that lies between the insertion of the [thoracic or] chyloferous duct, and the right ventricle of the heart. In dead subjects almost all the blood is found collected in the veins, while the arteries are usually empty. . . . In the cavity of the veins, at different intervals, there are certain very thin, light pellicles, called valves, which at one extremity, namely, toward the smaller twigs, are continuous with the interior venous coat, while at the other, [namely, toward the heart,] their edges are free. . . . They are frequently found near the divisions of the veins, or the junction of the branches; and sometimes are single, sometimes in pairs, sometimes in triplets, &c. The latter are placed anteriorly and posteriorly with respect to the body, while the former [or the single] have a lateral position; or *vice versâ*. (*Corp. Hum. Anat.*, lib. i., tr. i., cap. iv., p. 13—15; Bruxell., 1710.)

“If the crural vessels be exposed and tied, (for instance, in a living dog,) the vein swells up in its narrower part, that is to say, on the side of the ligature farthest from the heart, while the part that is broader and nearest to the heart collapses. The contrary happens with the arteries.

“As it is the office of the venous twigs to receive the blood from the little arteries, so we find that these two sets of vessels constantly either accompany or meet each other: but the larger venous branches are sometimes bound up with the arteries, and sometimes separate from them; and indeed not unfrequently the veins mount up over the arteries. . . . Moreover, not only are blood-vessels of different kinds connected with each other, but also blood-vessels of the same kind; frequently, that is to say, veins with veins, and arteries with arteries; so much so, indeed, that there are scarcely any considerable twigs running from the same trunk to the same region, but after their division again unite, at any rate by minute anastomoses. Most anatomists have hitherto considered such anastomoses to be confined to the regions of the head and uterus; . . . but they are beautifully seen externally in the skin of a foetus of six or seven months. (*Ibid.*, p. 12, 13.)

“The circulatory motion or circulation of the blood is as follows.

The blood passes from the trunk of the vena cava, and from certain of its branches, into the right ventricle of the heart, in part immediately, in part mediately through the right auricle. From the right ventricle it is expelled by the contraction of the heart into the pulmonary artery, by the little branches of which, distributed through the lungs, it is conveyed into the twigs of the pulmonary vein, and passes along the trunk of this vein to the left cavity of the heart, in part immediately, and in part mediately through the left auricle. From the left ventricle it is expelled by the contraction of the heart into the aorta, and by the ramifications of this vessel is distributed all over the body. That portion of the blood that is neither converted into solid substance, nor into any other matter extraneous to the circulation, passes from the little branches of the aorta into the little branches of the veins, and at length comes back through the trunk of the vena cava to the right ventricle of the heart, from which it started. . . .

“If an artery of a dog be tied, and punctured with a lancet above the ligature on the side next the heart, provided the animal be healthy, the blood will spirt out in a strong jet to the height of several cubits; and if the artery be left open for any length of time, the dog will die from loss of blood. If however the puncture be made on the other side of the ligature, very little if any blood will escape. But if a vein be punctured, the contrary will happen: on the side of the ligature next the heart no blood will escape, while on the other side a copious stream will be emitted, although not with such force as when the blood escapes from the arteries. . . .

“The sagacious and penetrating Leeuwenhoek endeavors to prove (Epist. 67) that the blood does not flow more rapidly through the large vessels than through the small. To demonstrate this position he constructed two tubes, and made them communicate with each other by means of smaller tubes, so that all together formed a continuous pipe. He does, in fact, prove that the liquid sent through one of the larger tubes moves with equal rapidity through the other. With respect to the smaller tubes, it is evident, that unless collectively they are of a calibre not inferior to that of the larger tube, the liquid must run through them more rapidly than through the larger. . . . The same most curious inquirer watched through a microscope the circulation of the blood in an eel (Epist. 67), and found it so rapid, that in the space of one hour, it amounted to a distance of 288 inches . . . or 24 feet. . . . [From this] he concludes, that in a man, the blood circulates from the heart to the extremities of the feet and back again, only twice and two thirds in an hour. And that in the same time it completes four times and a little more than one third of the whole circle, through the



extremities of the fingers ; eight times to the extremities of the head ; . . . and that within the hour, 14 times the quantity of blood in the body is forced from the heart," &c. (*Ibid.*, lib. ii., tr. iv., cap. iv., p. 263—269.)

117. BIDLOO delineates the exterior coat of the arteries as a reticular tunic, consisting of little nerves, blood-vessels, and membranous expansions, most of the ends of which are inserted into little glands, whose situation and figure are various, some being in groups, some in clusters, while others are vesicular and converge to a point. He displays the second or muscular tunic as a series of circular, or rather spiral fibres, the spiral fascicles being superimposed one upon another, and connected together by means of villous fibrils. The interior tunic is shewn to be made up of flat membranous expansions, lying straight along the artery. In representing the tunics of the veins, he delineates their outermost fibres as irregularly longitudinal, tensile and tendinous, attached by their extremities to certain fleshy tubercles, and to certain longitudinal lines of the same substance. He depicts the next tunic of the vein as a network, or plexiform membrane or integument of vessels, and as having innumerable glands attached to, and set in, it ; which glands are connected together by little fibres and vessels, that by their multitude form as it were a third specific covering. The above network constitutes the middle coat of the veins. Next he delineates the internal or third tunic, consisting of bundles of muscular fibres, running in a spiral direction. He also represents the veins as having, not only single valves, but sometimes as having two, three, and even five at a time, some of them conoid and pyriform, some semilunar, others semiorbital. Furthermore he states, that these valves lie at very different distances from each other along the veins. (*Anatomia Humani Corporis*, tab. xxiii., et explic.)\*

118. MANGET. "The body of an artery is composed of four tunics ; the first and outermost of which (the vascular and vesicular coat of Willis) appears to be nothing else than a network of innumerable blood-vessels, variously intertwined with each other, and with nervous offsets and fibres. These blood-vessels may be seen to advantage in the larger arterial trunks of recent subjects that have died without loss of blood. But they are rendered much more conspicuous

\* Swedenborg derived his account of Bidloo's tab. xxiii., not directly from Bidloo's *Anatomia Humani Corporis*, but from Manget's *Theatrum Anatomicum*, tab. lii., and expl. But as Bidloo's explanation of his plate is different from Manget's, and more intelligible ; and moreover as Swedenborg cites Bidloo's name as his authority, it has seemed advisable to adhere to the statement given by the latter author himself.—(*Tr.*)

by artificial injections of prepared wax, such as are made by the celebrated Ruysch. The second tunic was first discovered by this anatomist, who described it as a cellular coat, partaking entirely as it does of the character of that subcutaneous cellular membrane that is diffused throughout the body, and which, together with the fat enclosed in its cells, is generally enumerated among the universal integuments, under the specific name of panniculus adiposus. In the large arteries near the heart, this membrane perceptibly takes up a fatty juice emulged from the blood-vessels of the superincumbent tunic, and diffuses it, though less perceptibly, throughout the whole tract of the arteries. . . . It is in consequence of this juice, that the artery, when tasted, savors not a little of fatty matter. The cells of this tunic may be shewn either by inflation or by the Ruyschian mode of injection. The third tunic is termed by Willis, glandular, as being made up of innumerable minute white glands closely crowded together. These glands discharge a mucilaginous humor, which together with the fatty juice above mentioned, must in no small degree facilitate the motion of the underlying muscular tunic. . . . The fourth tunic is properly called muscular, since it consists entirely of two layers of muscular fibres ; that is to say, a circular or spiral, and a longitudinal layer ; their tendinous and nervous expansions being observable within. The motion of the arteries is carried on solely by means of this membrane ; the spiral fibres compressing and constricting the vessel, and the longitudinal elevating and dilating it, much in the same manner . . . as in the intestines. Willis adds to the foregoing another tunic, which he calls nervous. But this tunic is not distinct either in substance, nature, or office, from the muscular tunic, but is composed entirely of its longitudinal fibres and tendinous and nervous expansions intertwined, and therefore we shall not make it the subject of a separate description. We will here mention only, that the strength of the artery is derived entirely from the muscular coat, and that if this coat be lacerated, cut, or dilated by any force, external or internal, an expansion of the artery, or an aneurism, is the result ; for the intrinsic softness of all the other tunics causes them to yield at once to the pulsations of the blood. (*Theatr. Anat.*, tom. i., p. 192, 193 ; fol., Gen., 1716.) The veins have the same tunics as we have described in the arteries, but they are much thinner, and the cellular tunic, if it be not altogether wanting in them, can at any rate hardly be demonstrated. Moreover the muscular tunic, which in the arteries is a single structure composed of two sets or orders of fibres, forms in the veins two membranes. Thus the longitudinal fibres that in an artery form the inner order immediately underlying the spiral fibres, form in the vein a peculiar tunic, investing it



exteriorly, and which, therefore, is separated from the spiral fibres, which are situated more inwardly, by means of interposing membranes, vascular and glandular. But all the venous tunics are comparatively feeble, and particularly the muscular, which, as we have said, is divided into two," &c. (*Ibid.*, p. 201, 202.)

119. MORGAGNI. "Now, Manget, let us proceed with you to the arteries, the tubes of which you pronounce to be cylindrical. I grant that such is the dictum of some of the most learned anatomists. But still, on the other hand, you might have known from the anatomy of the ostrich, as given by the experienced Vallisnerius, that where the great artery of this animal for four inches and a half gives off no branches, it was clearly seen by . . . J. Dominicus Santorinus, . . . and Bernardus Zendrinus, to be, not cylindrical, but conical. . . . To say nothing of the number of the tunics, on which subject I have no wish to dispute, I observe, that some things which you and Verheyen assert respecting the characteristics of these tunics, I have no difficulty of recognizing in the arteries of oxen ; but whether they can be shewn by sufficient evidence to hold good in those of the human subject, I have my doubts. . . . Much more do I doubt . . . whether the fleshy fibres in the tunics of the arteries 'are spiral and longitudinal,' and serve the purpose of elevating and dilating the artery, as in the intestines ; just as if there were no other circumstances to be taken into account in the arteries, and as if ample reason for their elevation and dilatation were not to be found in the intrusion and forcible propulsion of the blood. And for my part, not only do I not acknowledge that there are any sufficiently manifest longitudinal fibres in the internal coat of the arteries, but supposing that there are none, I think I see how it is that others have sometimes fancied they could discern them. In fine, I observe in the arteries no fleshy fibres at all, except such as are annular ; nor do I find that in [your *Theatrum Anatomicum*], tab. li., fig. 4 and 6, Willis and Verheyen delineate any others. (*Adversaria Anatomica* ii., Anim. 38.) That 'the vena cava in the larger animals, that is to say, both in man and brutes, at its ingress into the heart, is entirely muscular,'\* will not easily be admitted by one who has seen the vena cava of the ox indeed, provided with a red and powerful muscle analogous to a well-marked sphincter, but has sought in vain for a like muscle in the human vena cava ; although I would not for this reason deny to the latter a muscular character and power." (*Ibid.* v., Anim. 15.)

\* It is to be observed, that in these extracts, and indeed throughout the *Adversaria Anatomica*, ii—vi., Morgagni is animadverting upon the *Theatrum Anatomicum* of Manget.—(*Tr.*)

120. HEISTER. "An artery is a pulsating, elastic, branched canal, conveying the blood from the heart to all parts of the body. 1. The arteries of the human body are, properly speaking, only two in number; namely, the pulmonary artery, and the aorta or great artery; of which two all the others, although distinguished by particular names, are but branches. 2. The figure of the arteries is conoid, running from a large diameter to a smaller. In the extremities of the body, however, the twigs become cylindrical canals, and terminate sometimes in reticular plexuses, sometimes in little brushes, spirals, glomes, &c.; and at length in serous vessels, veins, lymphatics, or excretory ducts. 3. The arteries are of a membranous structure, being made up of five coats, the first of which is vascular, the second cellular, the third tendinous, the fourth muscular (consisting of a vast number of annular fibres), and the fifth nervous. (*Comp. Anat.*, n. 291.) For I find . . . that five coats at least may be reckoned in the arteries, all of which are very distinct and manifest in the larger arteries, and particularly in the trunk of the aorta. . . . In the external coat numerous blood-vessels are visible. The second coat consists of numerous retiform plexuses, and is divisible into several layers, which nevertheless, as being homogeneous in substance, I have considered only as one coat. . . . The third coat is a firm and tough membrane, almost of a tendinous character. When this coat is removed, we come to a dense and thick tunic made up of a vast number of plain muscular fibres, surrounding the arteries like a circle or ring, and which tunic, by reason of its thickness, is also readily divisible into several layers. . . . Lastly, there is the fifth or internal coat, underlying the fleshy annular fibres, and termed the nervous coat. . . . I am at a loss to know the reason for which some anatomists venture to deny to the arteries the possession of a muscular coat, and of the requisites of muscle, (which requisites consist in a visible fibrous substance, and in the power of contraction and the exercise of motion;) for the annular fleshy fibres in the arteries are far more manifest and of far greater thickness [than in the intestines], and constitute various sufficiently remarkable reddish layers, (as I can shew to any one any day he pleases,) and in propelling the blood, exert a much more plain and forcible constrictile action and motion [than the fibres of the intestines exert in propelling the food]. Nor is it true, that muscular structures are incapable of ossification; for not to mention the sesamoid bones, which are often found here and there both in the origins and insertions of various muscles, the dura mater itself, (which in the opinion of recent anatomists is muscular,) and the very intestines, in both of which bony substance is occasionally detected, sufficiently disprove the position. (*Ibid.*, not. 63.) The veins are composed of a



membranous, a vascular, and a muscular coat, but these are much thinner than in the arterics. In some of the branches of the vena cava there are semilunar valves, which assist in the circulation of the blood ; but there are no valves in the vena portæ, nor in the pulmonary vein. (*Ibid.*, n. 298.) The vena cava commences by a large sinus from the right auricle of the heart, . . . and divides into two trunks, a superior and an inferior. The superior trunk is situated on the right side, and gives off the vena azygos, . . . the subclavian veins, . . . the external jugular vein, . . . the internal jugular vein, . . . the vertebral vein, &c. . . . The inferior trunk is remarkable for the Eustachian valve, and runs a very short course in the thorax, scarcely in fact for three quarters of an inch. Near the liver it makes singular inflections, which have passed unnoticed by recent anatomists, although delineated by Vesalius, and still better, as Morgagni informs us, by Eustachius, in his *Tabul. Anat.*, tab. xxv. From this trunk proceed the diaphragmatic or inferior phrenic veins, . . . the hepatic veins, . . . the renal veins, . . . the right spermatic vein, . . . the iliac veins, &c. (*Ibid.*, n. 296.) As to the Eustachian valve, . . . I find that Cheselden made the first mention of it, in the first edition of his *Anatomy*, p. 90, London, 1713. . . . He ascribes the discovery of it to Douglas. . . . It is probable that tab. viii., fig. vi., in Eustachius, *Opuscula Anatomica*, first published at Venice in 1564, . . . gave Douglas the hint for this. . . . But Eustachius does not call it a valve, but ‘a membrane of wonderful construction, placed before the mouth of the vena cava ascending from the liver, just where it begins to merge in the right auricle, occupying its anterior half, and forming a kind of reticulation.’ . . . Lancisi thinks . . . that this valve prevents the blood descending from the jugulars through the superior cava, from encountering too violently the blood ascending through the inferior cava. But Winslow is the author who has best of all described this valve, and explained its nature. He calls it the reticulated valve of Eustachius, and has given an elegant figure of it lunated and reticulated, and described its situation and connection much more accurately than any body who had gone before him. He observes that its concave part is turned upward, and its convex part downward ; and shews, moreover, that in looking for it in dissections, the posterior part of the cava, not the anterior, is to be opened ; otherwise the valve will not easily be found. He observes that it is very frequently absent in adults, in whom the foramen ovale is closed ; and is best seen and demonstrated in very young infants particularly, and in other subjects in whom the foramen ovale is open : and all the better if the parts be placed in a vessel of water. . . . He shews that it not only has the use that Lancisi assigns to it, but especially in the fœtus at birth, where it is most ob-

servable, also serves to prevent the blood from flowing back from the right auricle or superior vena cava into the inferior vena cava. (*Ibid.*, not. 69.)

“Many anatomists . . . divide the great artery into an ascending and descending trunk, in the same manner as the vena cava ; but in the human subject, this division of the aorta is not appropriate. For after rising about three finger-breadths as a single trunk, it forms an arch, and runs backward and downward through the thorax and abdomen. This arch, from the base of the heart to the place where it begins to descend, according to Morgagni, is about seven finger-breadths long ; and from the point where it begins to descend, it is called the descending trunk of the aorta, from which are derived all the arteries of the lower parts of the body. From the upper part of the arch, in the human subject, most commonly three large branches ascend ; the right branch then divides, more or less remotely from the trunk, into the right subclavian and right carotid artery ; the middle constitutes the left carotid ; and the third the left subclavian. . . . Sometimes, although rarely, I have found four ascending branches in the female ; the two outermost forming the two subclavian arteries, and the two middle, the two carotid arteries. (I have in spirits a preparation injected with wax, shewing this variety.) But it is very rarely, if ever, that there are only two ascending branches in the human subject, much less do we find only one ; and hence the aorta cannot be divided into an ascending and descending trunk. But in dogs, calves, and various other beasts, only one large ascending branch is generally observed, and from this circumstance the error mentioned above appears to have arisen : although even this single branch has commonly a small branch running beside it. . . . The branch that constitutes the left carotid, generally comes off by a perfectly distinct origin nearly in the middle between the first and third branches. . . . That the right carotid arises from the subclavian, is a fact which I most clearly recognize both in Drake’s figure [in his *Anthropolog.*, tab. xx.], and in the explanation he gives of it.” (*Ibid.*, not. 64.)

121. LANCISI. “To shew the structure of the arterial canals, we may take any branch we please ; but in order to render the experiment more palpable to the naked eye, let the great artery be selected, and having fitted into it a cylindrical piece of wood, let the artery be frequently wetted with hot water : then with the knife and probe let us proceed by degrees from the external parts to the interior ; and we shall find by this means that the arteries are composed of four distinct membranes. The first is purely villous, and consists of extremely fine filaments, which if we attempt to raise we shall see interwoven with



each other like the threads of the cotton-tree, or like the thin film of threads with which the cocoon of the silk-worm is surrounded. Within these filaments there is a complicated tissue of extremely slender vessels, both sanguineous and nervous. We next meet with a second membrane of a denser structure and more resisting. This membrane is thought by Willis to be glandular, and to me appears to be as it were a propagation from the pleura or interior membrane of the pericardium; for it has a similar solidity and texture, and is likewise provided with numerous longitudinal fibres. The third membrane at which we arrive is plainly fibrous, and is the thickest of all; so much so indeed, that with a little dexterity and patience it may be separated into numerous layers, as I have more than once seen; and what is particularly deserving of notice, the fibres of this coat, which are likened by Galen to the sinewy fibres [lacerti] of the stomach, are in reality not of one but of many orders, for the most part being spiral, that is to say, running obliquely in a gyre; which circumstance has caused some authors to assert that this membrane consists of circular and transverse fibres. . . . The fourth or last is the finest of all the membranes, but strong, and although it contains only the most minute foramina, is nevertheless transparent, and may be seen through when held up to the light. This coat of the arteries corresponds to that which lines the inside of the ventricles of the heart, and which being made up of a most dense tissue of villi, alone confines the more subtile and volatile particles [of the blood], which would otherwise no doubt in great part make their escape; for the looser texture of the other membranes could hardly avail to keep them in. In this membrane there are two other things to be noticed. In the first place, its inner surface is polished with a kind of oily glue, by which the passage of the blood is rendered more rapid, and the way lubricated. In the second place, (what we do not meet with everywhere, but only in certain parts, and chiefly in the large branches of the arteries,) we find a distribution of certain adipose follicles, which are clearly seen in the aorta without the microscope, and by which it is probable the fat is secreted and collected, and afterwards at the proper seasons gradually thrown out here and there, in order that the arteries may thus be kept lubricated with an oily substance of the kind, as we said above." (*De Motu Cordis*, &c., lib. ii., cap. ii., prop. vi.)

122. VIEUSSENS. "The arteries are provided with four coats, namely, with one common coat, which they put off when they enter into the interiors of parts; and with three proper coats, the middle of which consists of annular fibres, somewhat hard and resisting. The farther the arteries are from the heart, the smaller they are, and the

narrower in calibre. . . . It is very evident that in that motion of the arteries which is properly called dilatation, their coats are stretched in every direction beyond their natural degree of tension. Some have thought with Galen, that this extension depends upon a pulsific faculty; and others with Willis, that it depends upon the animal spirit. We cannot however but agree with those who maintain that the arteries are dilated by the blood. For as the blood in its exit from the heart, travels from the larger to the lesser arteries, on its way to the remoter parts, it must necessarily communicate its entire nisus to the parietes of these hollow pipes, and by means of its expansive motion, and of the impulse superadded to it by the contraction of the heart, overcome the resistance of the fibres of which the arteries consist, and in the same proportion dilate them. In this opinion we are confirmed by the following experiments, which were made with the greatest care in the presence of several competent witnesses. . . . We first placed in warm water a number of small tubes, of different length and calibre. In the second place, we fastened a dog to a table, laid open its abdomen, and tied its mammary and epigastric arteries; and laid its left kidney, spleen, stomach, and intestines, back on the right side. The superior muscular artery together with the corresponding vein, otherwise commonly called the adipose vein, being tied, we also secured the descending trunk of the aorta a little below the diaphragm, and a little above its iliac branches. We then opened the part of the vessel between the two ligatures with a scalpel, and pressed out the whole of the blood that it contained; and occasionally fomented the same part with a sponge wetted in warm water. We then introduced one of the little tubes that had been in warm water, into the cavity of the artery, so that the tube completely filled, without however much distending it. We tightly tied the artery down upon the tube with two ligatures, so that the aperture in it was included between them. We proceeded thus far with as much care as possible, and adopted the above measures lest the blood on entering the cavity of the tube should coagulate therein; and we now found, manifestly both to sight and touch, that when we untied the two first ligatures, the artery pulsated almost as strongly below the tube as above it. This experiment being completed, we again tied the artery a little below the diaphragm and a little above the iliac branches, and unfastening the two ligatures with which the artery was tied down on the tube, we drew the latter out of the cavity. We then plugged the cavity of the tube itself with a small piece of sponge, and immersed the tube in warm water; and while it was warming, we fomented the artery as in the other experiment, in order to restore to it its former degree of heat. This being done, we inserted the plugged



tube, now warm, into the cavity ; but this time we did not tie down the artery upon the tube : yet notwithstanding this, not a drop of blood escaped through the aperture made by the incision ; for the tube filled the cavity of the vessel. We then untied the two ligatures that had been placed on the artery, yet although this was done, and the part was fomented as before with warm water, there was no pulsation below the tube. . . . Let no one suggest, that the artery pulsated below the ligatures, not only because it admitted into its own proper cavity the effervescing blood expelled from the ventricles of the heart, but also because below the ligatures it was provided with nervous fibres, through which it received the animal spirit as the principal cause of its dilatation and contraction ; for during the foregoing experiments we freed and separated the artery from the nerves and all the neighbouring parts as far as was possible to be done. Taking all these facts into account, I must continue to be of opinion, that the dilatation of the arteries depends solely on the impulse and expansive force of the blood. . . . It may be well to observe, . . . that in the first experiment the artery always pulsated a little more feebly below the tube than above it, however large the cavity of the latter might be. . . . Furthermore, long experience has taught us, that there are many persons in whom (although a sufficient quantity of blood may be contained in their vessels, and the impulsive motion of the heart may be sufficiently strong) no pulse can be felt at the wrists or other parts of the extremities, when the extrinsic principles of the expansive motion of the blood have become effete and inactive. . . . In the first place we tied a dog's crural artery with two ligatures, and divided it across midway between them, and we then tied the crural vein. When this was done, the artery sensibly collapsed below the inferior ligature, while on the other hand the vein swelled up in the corresponding situation. Yet every one must see that the heart's impulse was intercepted, while the blood was moving in the above vessels below the ligatures. From which it is sufficiently clear, that the blood has in it a certain power of expansive motion, which by no means depends on the heart's impulse, and that by this power, with some assistance derived from the motion of the muscles of the legs and feet, it passed from the crural artery into the crural vein during the performance of the foregoing experiment. In the second place, a strong dog was fastened to the table, its abdomen laid open, and both its iliac arteries tied. The sternum being then separated from the diaphragm and ribs, and laid back towards the head, we as carefully as possible tied the ascending trunk of the aorta, and the other vessels of the heart near its base, together with the pericardium. The motion of the

heart thus entirely intercepted, we made a slight incision into the descending trunk of the aorta, when the blood spirted from its cavity with great force, and as it were in distinct jets ; which would by no means have been the case had there not been an expansive force in the blood." (*Neurographia Universalis*, lib. i., cap. iv., pp. 22—27 ; fol., Lyons, 1685).

123. MALPIGHI. “. . . In the silkworm, directly from the points or stigmata that are visible externally in the whole of the rings but the second and third, there arise certain remarkable ramifications of vessels,\* which run to all parts of the body. These ramifications are without any apparent trunk, but in each orifice [or stigma] are fitted ten considerable branches, and sometimes more, which terminate in one common opening or hiatus, so that this insect has eighteen plexuses of branches of this kind. . . . From this hiatus, or short trunk as it may be called, two circles [or tubes] arise, which run respectively to the plexuses situated above and below, thereby creating a mutual anastomosis from the head to the other extremity of the body. . . . These vessels ramify like arteries, for the further they proceed from the trunk, the finer they become, and in various parts they give off numbers of twigs, which mostly form reticular plexuses, such as may be observed in the leaves of trees ; and this is more particularly the case between the muscles and the skin, where the luxuriance of these vessels is so great, and their interweavings are so wonderful, that it is impossible to have a more beautiful spectacle than they present. They extend to all parts of the body, so that there is not a visible portion of it that is without them. They are of a blue or leaden color, which gradually becomes silvery, although it is found to be various in different specimens of this class of insects, for the most part being silvery, or pearly, but sometimes of a strawy tint, or suffused with a golden hue. (*Dissertatio Epistolica de Bombyce*; and *Ibid.*, tab. iii., fig. 1.)

“When a ligature is put upon the [frog’s] auricle and heart, and the motion and impulse prevented that might otherwise be communicated by the heart to the vessels, still the blood is sent by the veins towards the heart, so as by its force and quantity to distend the vessels ; and this lasts for several hours : but at length, especially if the parts be exposed to the rays of the sun, the blood ceases to be actuated with the same continuous motion, and fluctuates, as if impelled by fits, going backwards and forwards the same way ; which will occur even when the heart and auricle are torn off.” (*De Pulmonibus Epistola* ii.)

\* Malpighi regards these vessels as the pulmonary pipes of the silkworm, and has represented them with tracheal rings in his Figure.—(*Tr.*)



124. BAGLIVI made the following observations in a frog that he opened for the purpose. "At first the blood ran through the vessels with the greatest rapidity, as it were in straight lines. . . . These straight lines moved more rapidly in the middle (centre or axis) of the vessel, than about its sides; and the nearer they were to the sides, the less was their velocity. When the frog was almost dead, the above rectilinear currents were more slow, and instead of having a progressive motion, began to be deflected to the parietes of the vessel in various parts. . . ." The author also states that he "lightly touched the surface of one of the mesenteric veins with oil of vitriol, and immediately the current of blood was stopped through that vein, and retrograded into the veins nearest to it," &c. (*Opera: Dissert. de Experimentis per Infusoriam in vivis Animalibus*, exp. xi.)

125. LEEUWENHOEK'S experiments on the circulation of the blood in various animals are thus set down by Manget. "The first experiment that he made," says Manget, "was on certain pellucid microscopical parts, hanging, three on each side, from the head of a tadpole recently excluded from the ovum. In these parts, which of themselves were pellucid, he most distinctly saw the circulation of the blood going on in the vessels, from within to without, and from without to within, and not with an equable and continuous motion, but by most rapid and impulsive advances, which every now and then were observable. . . . In the tail of another tadpole of somewhat larger size, he detected more than 50 currents of blood, and that too, in distinct places, whenever the creature, which was kept in water, became still, and of its own accord moved under the microscope. Moreover he not only saw the blood conveyed in various situations by the smallest vessels from the middle of the tail to its exterior parts, but he likewise saw these vessels themselves inflected obliquely, and the blood carried back to the middle of the tail, on its way again to the heart. Hence it became evident to him, that the blood-vessels observable in this creature, and which we are wont to distinguish into arteries and veins, are one and the same class of vessels. . . . But in the place where he thus viewed the circulation, the arteries were not wider than to allow single particles of blood to pass through them without impediment. And even these particles, which appeared for the most part globular, occasionally assumed a tapering figure to suit the tenuity of an artery; although they are so minute that a hundred thousand myriad of them are not equal in bulk to a large grain of sand; whence we may easily conjecture how minute must be the vessels in which the circulation is carried on. Again, in a frog of larger size, he saw that the blood running in the great artery, and derived into a twig or little artery, was sometimes

suddenly stopped in its progress, and even retrograded till it was re-funded into the great artery, by which the beforementioned twig was given off; the cause of which circumstance he considers to be, that the blood had met with some slight impediment, or that some nerve or muscle adjacent to these little vessels, so pressed upon them as to obstruct the current. For after a short time, that is, when the impediment, as he presumes, was removed, the blood again resumed its ordinary direction and rapidity. In certain small fishes a little longer than the tadpole first mentioned, and dotted on the skin with black spots some of which resembled little stars, he observed, to his great gratification, the circulation [periodum] of the blood not in one only but in several different places. For on each side of the ossicles or little bones that give rigidity to the fins, every artery made a curve or inflexion, and thus constituted the beginning of a vein; and the agitation of the blood that flowed or was protruded from the large artery towards the extremity of the tail, and that afterwards returned through numerous little veins towards the great vein, was so considerable, as can scarcely be believed. Besides which, in the presence of many spectators, he submitted a variety of small fishes to the microscope; and with such success, that those who were with him, saw most distinctly, with the greatest admiration and rivetted attention, the circulation of the blood in several vessels at one and the same time. Now from the fact, that distinct currents of blood may be seen in the tails of such minute fish, he justly concludes, that in the human body the number of these currents must be incredibly great; and that it is no wonder that a flow of blood should take place when we are pricked with a needle or other small instrument; for from his own observations he is convinced, that in an area no larger than that of a finger-nail, there are more than a thousand distinct currents or circuits. In the tails or fins of larger fishes he clearly saw a great number of blood-vessels, admitting only single particles of blood. . . . More than once he saw an artery of this calibre blocked up; in which case, after the blood had for several times been propelled as it were by force through the artery, suddenly its course became a little retrograde, and then taking a different direction not far from the vessel it had found impassable, it there pursued its journey without impediment; the only difference being, that its motion was not now so rapid as before. From this circumstance he concluded, that the new course the blood took was not through a blood-vessel provided with a tunic or membrane, but that the blood had created for itself a canal by force. Again, in the caudal fin of an eel, he saw the blood running about through innumerable arteries and veins of various sizes. . . . In various places close to the



extremity of the fin, he could discern an elevation or rising in the most minute blood-vessels, corresponding to the moment of each fresh impulse that the blood received from the heart. In one species of eel, between the several ossicles that form the extremity of the caudal fin, he saw the blood circulating in vessels through which two or more of its particles could travel abreast, and many of the arteries also were there inflected, and constituted veins. He observed the circulation . . . in the fins or feet of fishes, in the wings of bats, in the wattles of cocks, and in the ears of rabbits. . . . When he dissected the artery or vein of any animal, and the vessel was emptied of blood, he found it pure and white on the inside, as if it had never contained blood at all ; in short, in nowise dyed or discolored. Hence he legitimately argues, that the vessels are formed in such a manner, that they keep even their fine juices ; although this rule is not to be extended to the minutest ramifications. When he dissected off the exquisitely thin, inner membrane of an artery, and submitted it to the microscope, he perceived, to his admiration, that it consisted of an incredible number of wonderfully minute parts running one through the other, and all connected together in the manner of a network ; and when he separated and examined the other part of the tunic that the former had covered, he found its fibres stretching round the artery, so that this tunic, being exceedingly tough, was adapted more to the expansion or contraction than to the elongation of the artery. . . . Sometimes he saw a clot of blood concreted in a vessel and blocking it up, and then gradually the clot was perforated by the constant stroke or impulse of the advancing current, until at last it transmitted a thread-like stream through the middle of it, and in fact acted as a tube inserted into the vessel." (Manget, *Bibliotheca Anatomica*, tom. i., p. 919—921 ; fol., Geneva, 1699.)

126. BOERHAAVE. "The red liquor called blood, which is distributed almost universally throughout the living body, is found in healthy subjects in peculiar vessels termed arteries and veins, or else in certain receptacles of an intermediate character, such as the venous sinuses of the heart, liver, and dura mater, the auricles and ventricles of the heart, the spongy substance or cells in the male and female genital organs, and perhaps also in the spleen. The arteries are membranous canals, conoid, oblique, inflected and branching, smooth on the inside, and destitute of valves, except in the heart. Their branches vary in their mode of origin. Generally they arise at acute angles towards the apex of the cone ; seldom at right angles like the intercostals. . . . They consist of five coats, the most external of which is thin and nervous on its exterior surface, but on the interior consists of a very thick network of ar-

terial vessels, derived from the coronary and other arteries, and interwoven with veins. This coat it is which attaches the artery to the proximate parts. The second is a thin and cellular coat, very dilatable when its cells are inflated; and which, by pouring forth an oily, fatty and lubricating fluid upon the muscular fibres, admirably fits them to perform their incessant contractions and expansions. The third coat is glandular, and probably is no more than a layer of the second coat, comprising principally fatty follicles that run to the fourth coat. This fourth coat is muscular, and is made up of highly elastic annular fibres, many rows thick, and divisible into a number of lamellæ. The fifth and last coat, which lines the internal surface of the artery, is thin and membranous, and appears to consist of longitudinal fibres, which are contractile, like those of the fourth coat. While life and health continue, this whole vessel moves and pulsates. But its extremities are very variously formed, so that in one part of the body its fabric is far different from what it is in another; different, for instance, in respect of the size of the aperture with which it originates from the trunk; in respect of the thickness of its coats, of the number of its branches, of the different angles at which these are given off, of their inflections, interweaving, division, &c. These arterial extremities terminate either in the beginnings of the little veins by a continuous canal, without any intermediate parenchyma [or cavernous structure]; or else in crypts, or follicles, or in the large or small cavities in various parts of the body; or in excretory vessels; or in particular sinuses, as those of the penis, clitoris, and spleen; or directly in secretory vessels; or perhaps, lastly, in a glandular pulp. The veins have almost the same figure and distribution as the arteries, but they are of larger capacity and perhaps are more numerous; besides which all their membranes are much thinner and more inert. They have valves, which are generally single at the insertion of the branches into the larger trunks, being oblong, and shaped like a glove-finger; but which are mostly combined in pairs in the strait trunks of the larger veins that are more remote from the heart and convey the blood perpendicularly upwards; and such is the structure and connection of these valves within the vessels, that they admit the blood from the smaller branches into the larger, but prevent its regress when the heart contracts, and sustain its column. The veins in the living animal have not naturally any pulsation, nor any throbbing motion like the arteries. Their extremities are various, as we observed to be the case in the arteries; some of their radicles commence from the little bibulous mouths of the cuticle; some, from the absorbent ducts placed all over the body, in the internal, hollow membranes that form crypts, follicles, or large or small cavities;



others arise immediately from the extremities of arteries, or else from certain singular analogous channels or sinuses, as in the penis, clitoris, and spleen; or lastly, perhaps from a glandular pulp. The whole of the arteries dispersed throughout the body are connected by continuity of channel and substance with the trunk of the aorta, where it arises from the left side of the heart. But those arteries that enter into the structure of the lungs, proceed after a similar manner from the pulmonary artery, which arises from the right side of the heart. . . . The orifices of the aorta and pulmonary artery at the heart are of equal dimensions. All the veins dispersed throughout the body have the same relation to the vena cava as the arteries to the aorta; but the cava forms a large sinus covered with a membrane like that of an artery, and thereby terminates in the cavity of the right auricle and partly in that of the right ventricle. But those veins that enter into the structure of the lungs, open by four great branches into a sinus similar to the former, which is prolonged into the left auricle and ventricle. . . . Both the arteries and veins are largest at the heart, from thence they gradually diminish in diameter, and almost constantly accompany each other closely in their distribution, through all the several regions of the body. The area of the orifice leading from the vena cava or auricle into the right ventricle, is to the area of the pulmonary artery as 47 to 114. (*Institutiones Medicæ*, n. 131—135.) If an artery be laid bare, and tied with a ligature, it swells and beats between the ligature and the heart; but becomes flaccid between the ligature and the extremities; and at the same time the neighboring arteries, which are still pervious, are found to pulsate with unwonted strength. And if an incision be made between the heart and the ligature, the artery continues to send out a swift and starting jet of blood, till the animal presently dies; but if the artery be even cut in two between the ligature and the extremities, not more than a few drops will escape. But for this experiment the artery should be single, and should not communicate by anastomosis with any large neighboring artery in the part beyond the ligature. (*Ibid.*, n. 141.) If a large vein be in like manner laid bare and tied, it swells between the extremities and the ligature without any pulsation, but appears empty and flaccid between the ligature and the heart; and if an incision be made in the former situation, the blood continues pouring out till the animal soon either faints or dies; but if in the latter, little or no blood follows; nor is it of any consequence what vein is selected, as we know by venesection. (*Ibid.*, n. 143.) An artery may be expanded by the distending impetus of the blood; yet this impetus ceasing, it has the power of spontaneously regaining its former calibre. For if the finger be thrust therein,

it forcibly compresses the same, and contracts of its own accord as soon as the finger is withdrawn. In a living animal the artery appears full, but it is found small and nearly empty in a dead human body, even where no blood has been lost previously to dissolution. The arteries resist inflation, forcibly repelling the air that is driven in ; and in contracting, they rest at the point of the least diameter. . . . There is not a perceptible part, however small, in the compass of the body, but has its little artery ; as we are taught by the bleeding that follows small wounds, by the phenomena displayed by the microscope, and by the process of injection ; and this remark applies even to the very middle of the bones, where we find both membranes, vessels, and humors. Nevertheless, all these arteries are offsets from the trunk of the aorta.” (*Ibid.*, n. 213, 214.)

127. Various modes have been adopted for calculating the quantity of blood in a living animal. Some fix the quantity in man at 25 lbs., others at 10, others at 8. It is said that in a sheep the weight of the blood, compared with that of the body, is as 2 to 22, and in a lamb as 1 to 22. Large quantities of blood have often been lost in hemorrhages from the nose. In one case 48 lbs. were lost in three days ; in another case, 75 lbs. in twelve days : see the *Acta Lipsiensia*. The pulse varies with all the different morbid affections of both body and mind ; thus it may be strong or weak ; or intermittent, for instance, beating rapidly twice, and pausing before the third beat ; or it may be palpitating. The ancients distinguished pulses into several varieties, such as undulatory, vermicular, formicating, bounding, mouse-like, double, unequally equal, irregularly hurried, serrated, &c. Some doubt the existence of what the ancients called revulsion, by which they meant the abstraction of the blood from an inflamed viscus, by venesection ; and of what they called derivation, by which they meant the determination of the stream in a new direction.



### INDUCTION.

128. THE blood, in order to flow determinately to its ends and uses, flows within tunicated vessels, through which the circulation is carried on; a circulation, namely, from the left ventricle of the heart, through the arteries, into the veins, and from the veins into the right ventricle; whence it returns through the lungs into the left auricle of the heart.

As the blood itself is of a threefold origin, degree, nature, composition, and name, so is also the tunic of its vessels; in order that both the continent and the content may act as one common cause of determination. The membranes, which are several in number, correspond to the several degrees of blood; one being prior to the other, more universal, more perfect, and more simple. All these membranes taken collectively, and connected by mutual superposition, inclose and convey the red blood: membranes fewer in number and more simple inclose and convey the purer blood: and one simple membrane incloses and conveys the spirituous fluid.

Consequently, in the vessels, equally as in the blood and membranes, there are three degrees of composition to be taken into consideration, all of which should be distinctly perceived. The vessels of the first degree are those commonly called blood-vessels; the vessels of the second degree are the exsanguious vessels; and the vessels of the third degree are the fibres of the nerves. In conformity with these various degrees of

vessels, the circulation itself is subtriplicate; namely, first, a less universal circulation, which is that of the red blood; secondly, a more universal circulation, which is that of the purer blood; and thirdly, a most universal circulation, which is that of the spirituous fluid.

While the red blood is passing from vessels of its own order into vessels of another order, it becomes divided into the purer blood, or into blood of the second order; the saline, urinous, or sulphurous atoms which had entered into the composition of that degree, being deposited at the mouths of ingress or division. A corresponding operation is carried on when the blood passes from vessels of the second order into vessels of the first, or into the fibres.

After reaching the fibres, the blood continues its passage through them, returns into the vessels of the second and third orders, and becomes again compounded by passing through degrees similar to those by which it had become divided. Such is the manner in which it performs its universal circle, neither the beginning nor the end of which is determinable, but by means of which there is nothing that the blood, in its own limited universe, does not continue, supply with moisture, nourish, renovate, form, actuate, and vivify.

The vessels, like all other things in the visible world, possess, each in their own degree, their determinate maximum and minimum, and proceed from their maximum to their minimum, and from their minimum to their maximum. Thus they proceed from large arteries to lesser and least arteries, and from least veins to largest; all of which are employed in conveying the volume of red blood, and constitute only one order of vessels. There is the same progression in vessels of the second order, which convey the less compounded blood; and the same again in vessels of the first order, or in the fibres, which convey the spirituous fluid. Hence the transition of the blood, membranes and vessels of one order into those of another, is not



effected by continuous attenuation or decrease, but by a division and separation of each unit or part.

The sanguineous volume itself, in whatever degree we consider it, is mixed heterogeneous, mixed homogeneous, and pure. While performing its own proper circle, it reduces itself from a mixed heterogeneous to a mixed homogeneous volume, and from a mixed homogeneous to a pure volume. For as it proceeds it purifies itself from the serum ; so that while accomplishing its transition into the veins, it becomes a pure volume ; the mixed heterogeneous and homogeneous substances being successively separated and ejected. Again, in the veins the blood passes from a pure into a mixed homogeneous volume, and from a mixed homogeneous into a mixed heterogeneous volume. The same process takes place in the volume of the simpler blood, and the same again in that of the spirituous fluid.

As both the blood and the vessels are of a threefold order, so also is every texture which is formed by the vessels ; as, for instance, the glands, which are the receptacles of the secretions, and the ducts of the excretions ; for they are compound, more simple, and most simple ; and according to the order to which they belong, they are called either glands, vesicles, or pores ; one of which is compounded of the other, and one is divided into the other.

In a similar order are carried on the secretions from the small arteries into the above glands ; as well as the excretions : likewise the commixtion of the secretions, and the reabsorption by the veins.

To the end that all these things may attain to their due effect, there is required a constant circulation of the sanguineous volumes ; namely, a circulation of the red blood from the left side of the heart into the trunk of the aorta ; from the trunk of the aorta into its branches ; from its branches into the smallest vessels belonging to that order ; from these smallest

vessels into the smallest veins, as well as into the numerous hollows and receptacles for the secretions. This circulation is performed by successive propagations of an undulation, each of which takes place within an imperceptible moment of time : in consequence whereof there arises in every part of the permeated vessels that sensible elevation which is denominated the pulse.

This little wave having received its first impulse from the heart, is afterwards moved forward by the whole arterial system, presenting a rapid current, which acquires an accelerated velocity ; so that in the minuter vessels belonging to that order, the transflux of the wave, which is so multifariously divided, is almost spontaneous : in the vessels of the second order, the transflux of the wave is still more rapid and more spontaneous : in the vessels of the first order, or in the fibres, the degree of velocity and spontaneity is indefinite and immense. The action of the fibres does not depend on the action of the great or single heart, but on the actions of an infinite number of corcula, or as it were little hearts, namely, the spherules of the cortical and cineritious substance, which are prefixed to each fibre in the brains and their two medullæ.

In order to direct and promote the circulation, there is required a certain general pressure, or equilibrium of pressure, of all the arteries, tending from the heart in the direction of the arterial extremities ; since without a pressure exercised by the whole arterial system, there is no circulation ; as indeed without a circulation no general pressure can exist or subsist. In order to promote this general pressure and circulation in the vessels, there is required a muscular tunic, provided with a multifold series of motive rings, and continued from the muscle of the heart to the capillary vessels. There is also required an interior membrane, whose office it shall be to collect these rings, and to determine them to the production of this general effect in the manner which we find obtaining in the arteries.



The case, however, is different in regard to the veins. In these there is no circulation, but a bare impletion and depletion, or a pressure upon the blood they contain equally in every direction, upwards, downwards, and laterally, as exemplified in liquids filling conical vessels. For in the case of the veins, the influx of the sanguineous stream is from innumerable origins of these vessels, and their reception of the stream does not take place at any regular and given moment, as in the case of the arteries, but at several different moments. This sanguineous and venous stream, moreover, discharges itself into the chambers on the right side of the heart by a solitary venous sinus; thus presenting an arrangement altogether different from the one we find prevailing in the arteries.

The general pressure and circulation of the sanguineous volume being given, and compared with the condition of the vessels and with the nature of the arterial and venous blood, it follows, that the arcana of the science of angiology may be referred to the following general heads. I. That proper liquids and elements be conveyed to the blood. II. That in the blood they receive a due commixtion. III. That they be duly insinuated into and presented to the blood. IV. That they be duly separated. V. That they be held in a state of sequestration. VI. That in this state of sequestration they be eliminated or reabsorbed. VII. That the very blood globule itself undergoes resolution and reunion. All of which processes must be in continual operation.

The apportionment, commixtion, and insinuation of the liquids and elements, in a word, the entire composition of the blood, is effected in the veins. But the separation, sequestration, and elimination, in the arteries. The division of the several parts of the blood is effected at the entrance into the vessels, while the blood is passing out of the vessels of one order into those of another.

The more complete therefore is the state of purification from serum in which the blood is conveyed immediately from the arteries to the veins, the more nearly does the circulation approximate to its natural and most perfect state. All other particles designed to form an admixture with the pure blood thus propagated from the arteries into the veins, are imported by innumerable recipient vessels, ducts, and pores, of divers orders, and are seized by the little veins. Thus it is that the arteries hold in aversion and reject those things which are not suitable to the blood, while the veins seek out and procure to themselves such as the blood necessarily and contingently requires for its renovation, and the animal kingdom for its preservation.

To prevent therefore any undue aversions of the arteries, or appetencies of the veins, as well as other contingencies, from proving detrimental to the animal economy, nature has adopted a precaution in the establishment of a perpetual communication of the vessels one with the other ; in the multiplication in every part of the system of causes appointed to effect one and the same purpose ; and finally, in the subordination of vessels of one degree to vessels of another degree. Whence the certitude of the effect is ensured, and the several causes operate in repairing whatever deficiency or waste had taken place in the things severally caused. Moreover, in order that the brains may be continually producing this effect by the agency of their own causes and first principles, and also lest, through continuity of communication, they should be affected by any vitiated states of the body, both the arteries and veins which are proper to the body, and also those which are proper to the brains, form communications with each other in a manner peculiar to themselves, and their motions are dependent upon different origins.

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129. In this general Induction, the reader is presented with the science of angiology, or the doctrine of the arteries and veins, so extended as to include the doctrine of the fibres, or neurology; the doctrine of the glandular system, or adenology; and the doctrine of the muscular system, or myology. Hence he will perceive that the experience premised can be of but little avail toward confirming the several topics of the preceding induction, inasmuch as it relates merely to the blood-vessels; and if I ventured beyond the bounds of this experience, or travelled over the ground through which the science of the blood would lead me, I should have to collect my proofs from the whole field of anatomy. What therefore is to be done? To extend the argument beyond the limits of the particular facts adduced, would be a hazardous enterprize; while, on the other hand, to confine it within those limits, would oblige us to take very contracted views of the subject. To avoid these inconveniences, I shall be under the necessity of occasionally interrupting the course of the argument, by the introduction of observations extracted from the several Parts which are to follow, and where the subjects alluded to are more fully discussed. See n. 1—12.

130. *The blood, in order to flow determinately to its ends and uses, flows within tunicated vessels.* For the tunics or membranes are small canals and banks as it were, by means of which the blood is conveyed and derived to its final destination. Thus the vessels, namely, the arteries and veins, are only the determinations of the blood; and such as is the form resulting from their coalition and complication, such are the common forces and vital effects of the system, and such their particular qualifications (n. 2). Such also are the mechanism and organization of the body, which so wonderfully correspond with the various physical and chemical modes of action and operation.

131. The very uses and ends themselves to which the blood is thus determined, are more and less universal; nay, there is one which is most universal. To enumerate them all, however, according to their several orders, would be foreign to my present purpose. The only thing which it concerns us at present to notice, is, that they all imply that *it is only by acting that*

*animated beings live.* Consequently, there is a necessity for motive fibres, out of which muscles may be formed, whence action may result; for action would by no means ensue, unless the blood received a determination by vessels. In the second place, the blood must be provided with all the requisites out of which glands are to be constructed, vesicles conglomerated, and pores made up. Here also we are led to see the cause of the cause of action, which would not exist unless the blood were determined by vessels. In the third place, out of these principiates there must be viscera framed, which are as it were mere muscular and glandulo-vesicular tissues, from which finally the edifice of the body is raised.

132. *Through which the circulation is carried on; a circulation, namely, from the left ventricle of the heart, through the arteries, into the veins, and from the veins into the right ventricle; whence it returns through the lungs into the left auricle of the heart.* This the reader may see illustrated in the works of Harvey, the authors above quoted, and other writers.

133. *As the blood itself is of a threefold origin, degree, nature, composition, and name, so is also the tunic of its vessels.* Respecting the blood, see n. 92. Respecting the tunics of the vessels, see n. 136 below. Both the blood and tunics are of a threefold origin, one being prior to the other. They are of a threefold degree, one being superior to, and more universal than, the other. They are of a threefold nature, one being more perfect than the other. They are of a threefold composition, one being more simple than the other. They are of a threefold name; thus there is the red blood, the blood formed of pellucid spherules or the pellucid blood, and the spirituous fluid, and nevertheless each of these is in its own degree blood, at least if we may speak by analogy, or by degrees of eminence. Again there is the vascular tunic, the vesicular tunic, the muscular tunic, and the nervous or membranous tunic, and yet each of these in its degree is a tunic. All these change their name, because as they undergo a change in regard to priority, universality, nature, and composition, so they undergo a change of appearance. Nearly all these as they pass through their several degrees, pass out, also, of the perception of one organ of sense into that of another, and in general, out of the perception of the external



senses into that of the internal, and so forth. For this reason they likewise pass into another sphere of words and ideas. See Chapter VIII. of this Part.

134. *In order that both the continent and the content may act as one common cause of determination.* The continent and the content, taken collectively, are called a blood vessel; for the vessel without the blood is merely a convoluted membrane, and the blood without the membrane is merely an indeterminate fluid. Hence as the vessel thus contemplated is but one thing, so also is the action of the vessel and of the blood collectively but one action or one single cause of determination. If therefore the blood and the tunic stand but for one vessel, and thus for one single cause, it follows, that there is a mutual dependence of one upon the other; if there be a mutual dependence, there must be a mutual correspondence, affinity and relationship between them; for the one gives birth to the other; thus the tunic is\* the tunic of the blood, and the blood is the blood of the tunic, the two possessing a unanimity, and being most perfectly accommodated to the production of every effect. Hence we see why the tunic of the vessels is, like the blood itself, of a threefold origin, degree, nature, and composition.

135. From these premises it follows, that the blood or its nature and mode of action being given, the quality of the tunic may be inferred; or the tunic being given, the quality of the blood may be inferred. For the blood is different in every different viscus through which it travels; it is of one sort in the brain, of another in the lungs, of another respectively in the spleen, pancreas, liver, kidney, stomach, mammæ, womb, and genital member; just as we find in every different viscus a different action, secretion, reportation, and exportation of fluids; or in fine, just as the ends and uses of the several parts of the body are different. The tunics are accommodated to the blood, and hence are correspondingly various. Thus Boerhaave says, speaking of the great arterial tree: "Its extremities are very variously formed, so that in one part of the body its fabric is far different from what it is in another; different, for instance, in respect of the size of the aperture with which it originates

\* Or the tunic is of the blood, and the blood is of the tunic.

from the trunk ; in respect of the thickness of its coats, of the number of its branches, of the different angles at which these are given off, of their inflections, interweaving, division, &c." (n. 126). And Verheyen remarks of the vena portæ, that "it has thicker coats, so as to appear in a measure to be an intermediate between the other veins and the arteries" (n. 126). Hence to every specific member of the body belongs its own specific science of angiology, adenology, myology, and neurology. How great the difference is between the arteries, veins and blood of the brain, and those of the rest of the body, the reader will see in Part II. The subject of the arteries, veins and blood of the other viscera, will be discussed occasionally as we proceed.

136. *The membranes, which are several in number, correspond to the several degrees of blood ; one being prior to the other, more universal, more perfect, and more simple.* The membranes of the arteries are generally considered to be four in number ; the same number also is attributed to the veins ; namely, an outermost, or fine, nervous and vascular membrane. Secondly, a vesicular or cellular membrane, by some denominated glandular. Thirdly, a muscular membrane, provided with motive rings. And fourthly, a nerveo-membranous tunic. A tendinous membrane is also mentioned by Heister as existing between the cellular and muscular tunics (n. 120). Of all these, the most universal is the innermost nerveo-membranous substance. The next in degree of universality is a certain nerveo-motive membrane discoverable in the smallest vessels. The next is the sanguineo-muscular. The others, such as the cellular and vascular membranes, are provided with a view to assist the single sanguineo-muscular membrane. Let us now proceed to the examination of each tunic in particular.

137. The most universal is the inmost or nerveo-membranous tunic, (so called because by some it is denominated nervous, and by others membranous.) This is evident from its extension and continuation even to the capillary vessels, and from these again over the veins, of which it forms the outermost covering : thence to the heart, where it joins itself with the inmost coat of the pericardium, and is afterwards folded back upon the external surface of the heart, and over the coronary vessels, by which



in all probability it is carried to the internal surface of this organ: thence to the lungs;\* from the lungs to the superior region, or to that of the brains and medullæ, and indeed even to the cortical and cineritious substance. For the internal carotid, leaving the pia mater on the exterior of the brain, and divided and subdivided into the minutest vessels forming the most wonderful ramifications, enters at innumerable places into the cortical chambers of the brain, nay, into every individual spherule of the cortex; and with its own innermost membrane constructs and convolutes it: whence the whole of that substance is by Ruysch denominated vascular. (*Thes. Anat.* i., ass. iii., n. 19, and *passim*.) Next it is continued into the medullary or fibrillary substance of the nerves, whence it returns to its own vessels. Thus in universality it surpasses all the rest. On this subject Lancisi says: "The fourth or last is the finest of all the membranes, but strong, and although it contains only the most minute foramina, is nevertheless transparent, and may be seen through when held up to the light. This coat of the arteries corresponds to that which lines the inside of the ventricles of the heart" (n. 121). And where he treats of the three membranes of the pericardium, he says: "The internal coat, which has all the appearance of being nervous and tendinous, is reversed, and doubled back towards the heart, so as to invest those portions of the great vessels that are contained within the pericardium; and it is also spread and extended, so as to cover the coronary arteries, and the whole surface of the heart." (*De Motu Cordis*, &c., lib. i., sec. i., cap. iii., prop. vi.)

138. That the membrane which follows next in degree of universality is a certain nerveo-motive membrane discoverable in the smallest vessels, the reader may see by consulting n. 142. On this subject Leeuwenhoek says, that "when he dissected off the exquisitely thin, inner membrane of a [minute] artery, and submitted it to the microscope, he perceived, to his admiration, that it consisted of an incredible number of wonderfully minute parts running one through the other, and all connected together in the manner of a network; and when he separated and examined the other part of the tunic that the former had

\* See *Animal Kingdom*, n. 420, 421 (*m*), 440 (*e*), and especially n. 507. (*Tr.*)

covered, he found its fibres stretching round the artery" (n. 125).

139. The membrane which follows next in degree of universality, is the sanguineo-muscular, which is perceptible to the naked eye, and the existence of which is hence generally known. Heister describes it as "a dense and thick tunic made up of a vast number of plain muscular fibres, surrounding the arteries like a circle or ring;" and he goes on to say, that its fleshy fibres "are far more manifest and of far greater thickness [than in the intestines], and constitute various sufficiently remarkable reddish layers," adding, "as I can show to any one any day he pleases" (n. 120). This coat increases in muscle in proportion as it approaches the heart, where it becomes condensed into one entire muscular body; it is however put off, when the internal carotid enters the cavity of the cranium, and climbs the brain. This tunic is therefore one which is proper to the vessels of the inferior region, or of the rest of the body, but not to the vessels of the superior region, or of the brain, and is less universal than the one above mentioned.

140. All the other membranes, such as the cellular and the vascular, are provided with a view to assist the muscular. In order for anything of a sanguineo-muscular nature to be formed, it must have vessels and fibres; wherefore, according to the description of Lancisi, the outermost membrane "consists of extremely fine filaments, which if we attempt to raise we shall see interwoven with each other like the threads of the cotton-tree, or like the thin film of threads with which the cocoon of the silk-worm is surrounded. Within these filaments there is a complicated tissue of extremely slender vessels, both sanguineous and nervous" (n. 121). For wherever there is a sanguineous muscle, at that place will meet together, by their several channels, arteries and veins; *there* also will be a confluence of nerves, fibres, little tendons; *there* likewise will be found vesicles, follicles, little glands, charged with their several contents; thence will be separated oily, pinguedinous matter, and lymph; and *there* will, finally, all those other functions be discharged which occur in the region belonging to the minute vessels. All these things are but the requisites and adjuncts of the sanguineo-muscular coat; they have each, however, such an



orderly arrangement, that their apparent irregularity is nevertheless in relation to the different modes of action, in itself most perfectly regular. Thus do the two outermost membranes only contribute to the perfection of the third, and on this account successively differ with the difference of the blood enclosed in the motive rings. A similar law holds in regard to the tendinous membrane mentioned by Heister (n. 120), which is employed in performing a sanguineo-muscular expansion and contraction.

141. The following is the sum of the foregoing remarks. The most universal tunic is the inmost nerveo-membranous. The next less universal is the nerveo-motive. The next less universal is the sanguineo-muscular; to which the two or three others are only subsidiary. One is *prior* to the other, as will be seen in the following Chapter when we treat of the Rudiments of the Heart. One is *more universal* than the other, as may be seen in n. 137, *seqq.* One is *more simple* or less compounded than the other; for the inmost, which is a thin membrane, as it advances becomes extremely attenuated. The same holds in regard to the muscular membrane. One is *more perfect* than the other, for each carries with it the same nature as that of its actuating fluid and first principle, and thereby is rendered more contractile, expansile, and elastic.

142. The reason for which I have classed in the number or degree of the membranes, a certain *nerveo-motive* membrane not yet generally known, is because the sanguineo-muscular membrane ascends by degrees, and becomes elevated and purified so as to assume this character. For on examination of the facts presented to us, we find that a muscle is of a fourfold origin, order, nature, composition, and name; there is, for instance, the muscle itself; there is the fleshy motive fibre, or the fibre of the red blood; there is the white motive fibre, or the fibre of the pellucid blood; there is, finally, the nervous fibre itself, which ultimately invests the smallest vessels (n. 138), wherefore the membrane thence produced ought to be called *nerveo-motive*. The reader will see that the muscles are thus graduated, in my Part on Myology. In the meantime, let this substance be assumed as a membrane, as inhering in the sanguineo-muscular, as successive to it; hence as prior, more universal, more simple,

more perfect : and we shall then see, whether in the course of our investigation, effects in general indicate this to be a genuine membrane ; for since autopsy cannot determine the question, we must come to our conclusion by induction alone (n. 10, 16).

143. *All these membranes taken collectively, and connected by mutual superposition, inclose and convey the red blood.* This is a fact, which, as it is attested by all the learned, is undoubted. The smaller vessels, which forward the blood of the same order as themselves, or the red blood, appear to consist of as many integuments as the larger, but with a difference according to the muscular coat, which, where it is adorned with fleshy fibres, has also a superstructure formed of the vascular and cellular subsidiary membranes ; but where it consists of fibres or motive rings, which are white, or belonging to the pellucid blood (n. 142), is distinguished by other succenturiate, auxiliary philyræ, the office of which consists in carrying down the more simple blood. This is the reason for which when there is a cessation of fleshy substance in the rings of the larger vessel, the [cellular] tissue begins to cease, as well as the vascular network, and the medley of vesicular substance observable in the last coat : it is the reason also that other coats succeed which are delicate and analogous to the former, and that in the place of visible cells and initiaments of glands there exist a porosity and invisible pollen. When Leeuwenhoek “dissected off the exquisitely thin, inner membrane of an artery, and submitted it to the microscope, he perceived, to his admiration, that it consisted of an incredible number of wonderfully minute parts running one through the other, and all connected together in the manner of a network ; and when he separated and examined the other part of the tunic that the former had covered, he found its fibres stretching round the artery” (n. 125). Hence it follows that,

144. *Membranes fewer in number and more simple inclose and convey the purer blood.* Namely, the nerveo-motive membrane, and also the inmost, which is successively attenuated.

145. *And one simple membrane incloses and conveys the spirituous fluid ;* namely the inmost and most universal membrane, which interiorly investing and accompanying the internal carotids, and having laid aside the muscular coat, and in the place



of the vascular and cellular membrane having acquired membranous coats from the dura and pia mater, penetrates even into the cortical and cineritious substance of the brain, thence into the medullary substance and first beginnings of the nervous fibres, in which is enclosed the spirituous fluid, which is conveyed within a simple superficies.

146. *Consequently in the vessels*, (considered as signifying both the continent and the content, or the membrane together with the blood,) *equally as in the blood and membranes, there are three degrees of composition to be taken into consideration, all of which should be distinctly perceived. The vessels of the first degree are those commonly called blood-vessels; the vessels of the second degree are the exsanguious vessels; and the vessels of the third degree are the fibres of the nerves.* That the exsanguious vessels succeed, and are in continuity with, the vessels of the red blood, is evident from the coverings of all the viscera, and of their several parts; it is evident from the whole tunicated circumference of the body, particularly from the face, reddening as both do at one moment with an influx of blood, and at another turning pale and livid; the color changing from a burning crimson to an opaline and white, and from the latter again to the former. If the mind is affected with grief, fear, shame, revenge, anger, &c., or if any disease attacks the members, or they become inflamed by ulcer, schirrus, or gangrene; or if the skin is irritated by a stripe, by a wound, or a fether, the red blood immediately rushes to the part, and fills with itself the exsanguious vessels. The case would be otherwise if these vessels were not in successive order, or not in continuity with the blood-vessels. The same fact is attested by the exquisitely rosy skin of infants; by the lurid and pale skin of old men; and by the immense tide of insensible and sensible effluvia which are expired from the system and inhaled into it; by the very structure of the cuticle and epidermis itself; by its sensation and that of the other organs; by the privation of sensation arising from loss of blood; by the transition of blood into the exsanguious vessels of the brain, such as occurs in sleep, lethargy, torpor, and swooning; by the pellucid vessels of insects and of small worms; by ocular evidence; for from his own microscopical observations, Leeuwenhoek “argues, that the vessels

are formed in such a manner, that they keep even their fine juices; although this rule is not to be extended to the minutest ramifications" (n. 125). He states likewise, that he saw vessels traversed by divided blood, or by plano-oval spherules.<sup>x</sup> The existence of such vessels is very clearly shewn by the Sanctorian perspiration, which is thus succinctly and ably described by Boerhaave: "There are other exhalant vessels under the little scales of the epidermis, opening obliquely, and of such exceeding fineness, that Leeuwenhoek reckons that 125,000 of them open in a space that may be covered by a single grain of sand. By these vessels a most subtile humor is constantly transpiring from every point of the body. . . . The exhalation of this humor is carried on by the whole external epidermis, as well as by the cuticle of the mouth, the nares, the fauces, the larynx, the lungs, the œsophagus, the stomach, the intestines, the bladder, and the uterus: hence its quantity is greater than that of all the other excretions put together. In fact, in the climate of Italy, in a person in the prime of life, who enjoys easy circumstances and takes moderate food, the perspiration which exhales from the external skin, the mouth, and the nares, is equal in weight to five eighths of the aliment taken into the body." (*Inst. Med.*, n. 426, 427.) It necessarily follows, therefore, that this immense crowd and medley of most subtile aliments are as truly conveyed through exsanguious vessels by a continued passage into the blood, as that they are afterward carried away out of it.

147. In the third order of vessels are ranked the fibrils of the nerves, but they are not in succession with vessels of the second degree, except in the cerebrum, cerebellum, medulla oblongata, and medulla spinalis. This you will see confirmed by numerous evidences in Part III., on the Cortical and Medullary Substance of the Brain. This substance, called the cortical substance, is intermediate between the vessels of the blood and the medullary fibres. For on the one hand it maintains a relation to the arteries, on the other to the fibres, and thus it affords a means of transition from the one to the other by continuing the fluid of one into the other. Consequently it is through the medium of this substance that the blood acts upon the organism of the brain, and *vice versâ*; or that the affections



of the brain and those of the rest of the body have communication with each other. Therefore, by the law of continuity, a fibre is a vessel of a superior degree, or a vessel by way of eminence, in the same manner as the spirituous fluid is blood by way of eminence. Thus are there three orders of vessels, according to the proposition.

148. *In conformity with these various degrees of vessels, the circulation itself is subtriplicate; namely, first, a less universal circulation, which is that of the red blood; secondly, a more universal circulation, which is that of the purer blood; and thirdly, a most universal circulation, which is that of the spirituous fluid.* Not that there are three separate and preëstablished circulations, but the same circulation continued into three, subordinated one to the other, so that in respect to its operations and mode one is more universal than the other. They are thus distinct from each other, while at the same time, being connected, they have a mutual relation one to the other, like that of the cause to the thing caused, the prior to the posterior, the superior to the inferior. I speak not here of the circuits of the other humors, as enumerated by Nuck, such as the saliva, gastric juice, pancreatic juice, bile, lymph, &c., since their circuits are but special and particular, and are dependent upon that of the blood. For the gyre of the spirituous fluid produces itself into the gyre of the purer blood, and the gyre of the purer blood into that of the red blood; whence there arises and lives, by an eternal copula and infinite circle, a unanimous harmony between the circulations, which are nevertheless perfectly distinct. This brings to light the reason for which the blood acts as it were in the office of a triumvirate, or for which it is of a threefold origin, order, nature, and composition. In fine, we here see the reason of the several statements made in the preceding chapter. This circle, however, we design to consider still farther.

149. *While the red blood is passing from vessels of its own order into vessels of another order, it becomes divided into the purer blood, or into blood of the second order; the saline, urinous, or sulphurous atoms which had entered into the composition of that degree, being deposited at the mouths of ingress or division.* This is a continuous effect of the cause; an effect evinced by the con-

glomeration and conglobation of the vesicles; likewise by the secretions in the extremities of the vessels, such as prevail in all the glands and muscles, whether they are in the mouth, fauces, gullet, stomach, intestines, mesentery; or in the spleen, pancreas, and liver; or in the lungs, bronchia, and trachea; or in the brains and their medullæ; or in the skin universally; wheresoever any pinguedinous, oily, lymphatic, volatile humor charged with effluvia, is met with.

150. *A corresponding operation is carried on when the blood passes from vessels of the second order into vessels of the first, or into the fibres.* Such, for instance, as those in the cerebrum, cerebellum, medulla oblongata and medulla spinalis, which are the native sources of the fibres and of the three fluids, and where a discription and division of the purer blood is carried on, similar to that of the red blood, before it passes into its higher circuit. This blood, in order to become spirituous fluid, must be released from the ethereal elements that temper, copulate, determine, and perfect it. (n. 91, 92, &c.) These atoms, when thus liberated, present themselves under the form of an oleaginous moisture. That such a moisture is to be found in the above natal regions, is proved by the experience of numerous persons; at present, however, I shall refer only to that of Pacchioni. “Besides,” says he, “what shall I think of the oleaginous lymph that is found between the pia mater and the tortuous and deep convolutions of the brain? Can it be supplied by the cortical glands of the cerebrum and cerebellum? No; for if these be wiped dry, you will not find any further humor proceeding from them. . . . But on the other hand, the whole inner surface of the pia mater, if wiped dry, is always spontaneously moistened, and is covered throughout with a whitish mucus, although it be separated from the dura mater and cortex cerebri; wherefore it seems impossible not to acknowledge in the porosities and lymphatics of the pia mater, the true sources of this abundant humor. . . . On this subject, Vallisnerius not long ago reminded me of an observation made by the diligent Ruysch, to the effect that ‘the pia mater . . . is in various places enriched with fat.’ (Ruysch, *Thes. Anat.* v., n. 13, not. i.) Moreover, if you touch the cortex of the brain with your finger, you will not fail to notice that it is extremely smooth, and covered with as it



were a most subtile oil ; a fact which I have learnt, not without surprize, from very frequent dissections," &c. (*Epistolæ Physico-Anatomicæ* ; epist. iv. ad Fantonum ; in operibus, p. 117—119 : ed. 4, Romæ, 1741.) The reader will see other remarks on this subject, in n. 199, ad fin. ; and again in Parts II. and III. of the present work.

151. *After reaching the fibres, the blood continues its passage through them, returns into the vessels of the second and third orders, and becomes again compounded by passing through degrees similar to those by which it had become divided.* That the nervous fibres have their termination solely in vessels, and that while embracing these vessels they are continually expiring their life or the fluid proper to them, is a circumstance which might be demonstrated by a variety of proofs, were I at liberty to extend this argument beyond the limit of the facts which preface the present chapter. The theorem however hinges upon the following demonstrations: first,—that any fibre, when exfasciated from a nerve, everywhere associates itself with some blood-vessel, and circumscribes the tunic of that vessel or of its motive ring. Secondly,—that when these two are thus wedded together, the fibre infuses into that vessel alone its own genial spirit. In the case of rudimentary stamina and fluids, both of which are so remote from the sight, there can be no such thing as ocular inspection ; yet we are enabled to make a just inference from those general phenomena, which being the effects of a number of the smallest efficients, come at length within the cognizance of some one of our senses, and thus present themselves to observation.

152. It is stated then, first, that a nervous fibre continually associates itself with some vessel. This is manifest from the following considerations, that in every part, even in the minutest corner of the body, there is sure to be found some vessel of one or the other order,—a vessel which is as it were an all in all ; that a nervous fibre cannot run in any direction without meeting one of these vessels ; that we can perceive by the eye in not a few instances that it entwines these vessels, ties them together, and folds them in its network, as is the case in the lungs, spleen, glands, muscles ; that it floats about them like mucus and froth, and creeps round them like ivy, as in the carotid and

intercostal arteries, in the branches of the azygos, and in all the other arteries and veins; that each vessel is encompassed with motive circles, no motive fibre of which is without a nervous fibre. Consequently the one only force and substance proper to a muscle, is a vessel thus fibrated; that is to say, the force and substance proper to a muscle is a nervous fibre. There is one particular experiment of Lancisi which illustrates the present subject. His words are these: "We once macerated . . . a human heart . . . in water . . . for forty days, . . . and on examining its then flaccid substance, we found it consisting entirely of three different kinds of components; namely, first of blood-vessels; secondly, of nervous branches and villi; and lastly, of a confused medley of fibres, formed of a vascular and nervous network. With respect to the nerves, we could clearly see that they everywhere accompanied the blood-vessels, and always became greater, and were augmented, within the heart, leading to the inference that the heart itself is a peculiar origin of nervous structure. For the tendons of the valves and columns of the heart are all interwoven with nerves, so that it is surprising to see a twine and mesh of them in every part, and particularly in the internal parts, and in the vicinity of the mouths of the large vessels." (*De Motu Cordis*, &c., lib. i., prop. lii., ad fin.) In other parts of his writings he likewise proves, that the tendons of the same heart, which are numerous, had been formerly, or during the period of infancy, muscular fleshy substance.

153. It is stated, secondly, that when the vessels are thus wedded to the fibre, the fibres infuse into the vessels their own genial spirit. This follows from the former statement, since it is in the vessels that all the fibres have their termination, and that the blood experiences a vivification at every point of its progression. For this reason the most universal tunic which ascends into the order of the simple fibre (n. 137) is the inmost, and subtends in the arteries the motive rings, for the purpose of immediately transuding a perpetual dew. The author last referred to describes this innermost membrane as containing "only the most minute foramina," and says that "being made up of a most dense tissue of villi, [it] alone confines the more subtile and volatile particles [of the blood], which would other-



wise no doubt in great part make their escape :” and he adds that “in this membrane there are two other things to be noticed. In the first place, its inner surface is polished with a kind of oily glue. . . . In the second place, (what we do not meet with everywhere, but only in certain parts, and chiefly in the large branches of the arteries,) we find a distribution of certain adipose follicles,” &c. (n. 121).

If the contrary were the case, how ineffably vast must be the tide, not to say the ocean, of this fluid, of which from morning to evening the muscles would be emptied ; since the fibres are in a state of perpetual exercise, and with a view to supply the muscles with their proper forces, in a state of perpetual exhalation. Were this fluid to fly off, the body would soon be deprived of life, nor would the brains be capable of conceiving and excluding a fresh and adequate supply. How careful nature has been with regard to the preservation of this most vital, this principal fluid, may be inferred from the other liquids which are vivified by it. For the more abundantly these are enriched by it, the more carefully are they by appropriate circuits conveyed to the blood : so that instead of being lost, nature has rather intended that not the least of it should be dissipated or perish, or should be sent by way of the blood in any inward or in any outward direction without fulfilling some appointed use.

154. *Such is the manner in which it performs its universal circle, neither the beginning nor the end of which is determinable, but by means of which there is nothing that the blood, in its own limited universe, does not continue, supply with moisture, nourish, renovate, form, actuate, and vivify.* The nature of the continuity of the circulation of the fluids, and of the expansion of the solids or vessels, (both the circulation and expansion being alike perpetual,) is clear from the statements already made. But although a universal circle would seem to be without beginning or end, there are nevertheless certain demarcations as it were, certain waymarks or stations between the sanguineous sphere of one degree and that of another, which serve to ward off the red blood in its undivided state, and prevent it from making, by a continuous current, an irruption into the circle of blood of another order. Similar precautions are taken to prevent an

irruption of the purer blood into the region of the spirituous fluid ; although in both cases when the brain relaxes its control, the gates are as it were burst open, and a rush of blood into a higher circle than its own takes place in consequence (n. 146). In like manner there are nodes and as it were cardiacal vesicles turgid with blood, many of which are visible in the muscular texture, in the places of confluence, or on the confines of the sanguineous circulations. All these are opened and shut at the option or by any affection of the brain, and when they are shut the blood is under the necessity of performing its own infinitely various circuits. This we are at liberty to infer from the facts witnessed by Leeuwenhoek, who detected in the tail of a tadpole “ more than 50 currents of blood, and that too, in distinct places.” And “ in the place where he thus viewed the circulation, the arteries were not wider than to allow single particles of blood to pass through them without impediment.” In a frog, “ he saw that the blood running in the great artery, and derived into a twig or little artery, was sometimes suddenly stopped in its progress, and even retrograded till it was refunded into the great artery, by which the before-mentioned twig was given off.” He adds that in the human body, “ from his own observations he is convinced, that in an area no larger than that of a finger-nail, there are more than a thousand distinct currents or circuits” (n. 125). That there are little stations or internodia of this kind in the body, can be very clearly proved from the cortical and cineritious substance of the brains, which is intermediate between the small blood-vessels and the fibres, and from which we may argue the existence of similar small stations or internodia in the body. Consequently we shall revert to this subject after we have first treated of the nature of this substance.

155. From this threefold circulation of the blood, which we have now explained, we see the nature of the harmony and connexion existing between the superior and inferior degrees. We see, for instance, that compounded blood contains within itself, in simultaneous order, each entity respectively of the simpler substances ; that the membranes enclosing the blood are connected with each other by mutual superposition ; and that in the same order in which the blood is divided they are purified



and exfasciated. These and numerous other facts connected with the subject, may give rise, as soon as we have completed our anatomical course, to a small work, on *Coestablished and Reestablished Harmony*.

156. *The vessels, like all other things in the visible world, possess, each in their own degree, their determinate maximum and minimum, and proceed from their maximum to their minimum, and from their minimum to their maximum.* For it is one of the rules in the doctrine of degrees, that a particle of any volume or homogeneous mass, constitutes its least volume or its least mass, or that this particle is a small volume or small mass in its smallest term or boundary, or is a unit of the volume or homogeneous mass in which it is. This particle or unit, how often soever it may be repeated, in whatever numbers it may be congregated, however it may be increased in multitude; or on the other hand, to whatever fractions its aggregate may be reduced, however it may be diminished in number, or decreased in multitude, yet never makes any transition into an inferior or superior degree. Thus water, oil, spirits, whether we assume a part of it, a small drop, a streamlet, a lake, or an ocean, does not cease to be water, or oil, or spirits. In the same manner, air or ether, whether we assume a part of it, a volume, a whole atmosphere, or a whole universe, nevertheless does not cease to be air or ether. Common salt, nitre, alum, stone, metal of any given species, whether it be a portion, a mass, a mountain, does not cease to be salt, stone, or metal, belonging to that species. The fluid consisting of plano-oval spherules, whether it fill a fibril or the smallest filament of a nerve, a siphon, or a bladder, remains nevertheless one and the same fluid. The same rule holds in regard to all other things, the division of which continues, without any change of nature, even to their component units, or the constituent elements of that degree. Unless our conceptions on this subject be clear and distinct, we shall have only an erroneous idea of the nature of divisibility and composition. The several single parts of a whole are as common numbers and rational integers, which are homogeneous with the units by which they are determined. The case is otherwise when they are raised to their roots, for then we come to another kind of unit, from which are formed other relative

numbers, the multitude and quantity of which, in relation to the multitude and quantity of the former, are heterogeneous. A similar law is observed by the blood, tunics, and vessels. *Thus they proceed from large arteries to lesser and least arteries, and from least veins to largest; all of which are employed in conveying the volume of red blood, and constitute only one order of vessels.*

157. *There is the same progression in vessels of the second order, which convey the less compounded blood; and the same again in vessels of the first order, or in the fibres, which convey the spirituous fluid.* This is a consequence of the former rule. In regard to the fibres, however, the same law does not altogether obtain as in regard to the blood-vessels. For instance, as the fibres progress, they do not in the same manner decrease in size, but accumulate into a fascicle, and however large this fascicle may be, it comprises only fibres of the first order. The fascicles, which are also the beginnings of nerves, and which in the medulla spinalis are called anterior and posterior, are there congregated into one nerve, which, however large, includes only nerves of the second order. Consequently a fibre is a unit of the first order, a fascicle of fibres a unit of the second order, and a nerve a unit of the third order. In the first the unit is determinate, in each of the two latter it is indeterminate, inasmuch as they are diminished in the number and multitude of the component units, in proportion as they descend into the several provinces of the body.

A similar law holds in regard to the spirituous or nervous fluid, as in regard to the fibres. Thus, for example, the very fibre itself, or fibre of the first order, carries within it a most highly defecated and most pure fluid. But between the first fibres, or in the spaces interposing between them, a fluid which is less spirituous is carried. The fascicles, however, where no blood-vessels accompany them, carry within them a lymphatic or other fluid, which is commonly called the nervous fluid. Each of these nevertheless is spirituous fluid, but in the first fibres it is pure, in the fibres of the second degree it is mixed homogeneous, in the fibres of the third it is mixed heterogeneous. That the fibres are distinguished one from the other, in the same manner as the fluids of the fibres in the brains and me-



dullæ, and that also in the body they are thus separated, will be seen in Part III., on the Substances of the Brain; and in Part IV., on the Tunics of the Brain; as also in the several Parts on the Nerves, Muscles, and Glands. What the condition is of vessels of the second order, or those which convey the purer blood, may appear from the ratio of the fibres as compared with that of the red blood, for they are the intermediates between the two, and from two given extremes may be educed by analysis the relation of the means.

158. *Hence the transition of the blood, membranes and vessels of one order into those of another, is not effected by continuous attenuation or decrease, but by a division and separation of each unit or part.* For blood is to be divided into purer blood (n. 149): a nerve is to be separated into fascicles and fibres (n. 157): a muscle is to be separated into fibres more perfectly and simply motive (n. 142): a membrane covering the blood is to be invested with a more simple fibre, and also to be separated (n. 136—143). In this manner it is that a vessel with blood thus divided, and with a membrane thus elevated or separated, ascends out of a lower into a superior sphere.

159. For the sake of more clearly understanding the subject, let the several first entities of any one degree be compared with units. A unit of an inferior degree is composed of aggregate units of a superior degree, but in addition to this there must be a third accessory substance, which gives it determination, copulates, and perfects it. In the blood this third accessory substance is the volatile salt, whether sulphurous or urinous; in the fibres it is the tunic sheathing the collective fascicle: consequently, the *third substance*, adequate to the former and connecting it, is either *internal* or *external*. Hence a unit thus compounded, before it loses its nature or reascends into the sphere of superior units, must in like manner be divided,\* unbound, or separated; for instance, the blood must divest itself of its saline corpuscles, and the nerve of its integuments.

160. A unit of a superior degree is compounded successively, whence it follows that it is also resolved successively. For the blood, membranes and vessels coalesce each of them succes-

\* *i. e.* Set free of the sheath and detached from the fascicle, as in the case of the nerve. (*Tr.*)

sively, as the next chapter will more amply explain. By a similar succession they are also respectively resolved, as they ascend from one circle into another.

161. Hence it follows, that unless, so far as regards the blood and its vessels, the animal kingdoms proceeded most distinctly from one degree into another, and thus into their last degree in the brains, they could by no means live as they now do. For did they not thus proceed by degrees, the brains never could flow from principles and causes into their principiates and causates, or they never could conformably to them determine effects; they never could be either in a state of conatus, or excite actual motion; they never could will and perform actions in the body, much less could they prescribe laws to organs and members of inferior rank. In things simultaneous, action is simultaneous; in things successive, action is distinct and ordained, or according to a certain order. Animal nature is as it were *all* in its pure and least principles, nor does it observe any laws but those of the universe. The purer it is in its substance and force, the more universal and perfect is it in acting and prospectively providing. The more compounded it is, the more particular and limited is it. For from its pure and least principles it has relation to everything; in its compounded state it has a relation to some one thing in particular; it circumscribes itself with ends, very conspicuous and definite, whenever it compounds itself, but it is in relation to the neighboring parts that it forms its limits, in order that from its own pure principles it may be enabled to maintain a relation to every state of the whole compound. For by means of the fibres, which are animated with spirit, it descends to the respective vessels and to the integers of vessels, which it compounds into a ratio to the neighboring parts, and then by means of a connecting bond of union between the two, establishes a reciprocal concordance between them, in order that both may thus be kept in subordination to the brains.

162. *The sanguineous volume itself, in whatever degree we consider it, is mixed heterogeneous, mixed homogeneous, and pure. (See above, n. 104, 105, 106.) Therefore, while performing its own proper circle, it reduces itself from a mixed heterogeneous to a mixed homogeneous volume, and from a mixed*



*homogeneous to a pure volume. For as it proceeds, it purifies itself from the serum; so that while accomplishing its transition into the veins, it becomes a pure volume; the mixed heterogeneous and homogeneous substances being successively separated and ejected.* This is testified by the excretion of the urine, the sweat, the Sanctorian perspiration, and by a variety of other things. *Again, in the veins the blood passes from a pure into a mixed homogeneous volume, and from a mixed homogeneous into a mixed heterogeneous volume.* For in the same order in which the blood is divided in the same it is compounded. *The same process takes place in the volume of the simpler blood, and the same again in that of the spirituous fluid.* To collect the various testimonies in support of these several positions, would require me to range the fields of natural chemistry, adenology, and pathology. Still it is necessary to mention and to insert them in their proper order, with a view to preserve the connection between the different parts of our subject. As I cannot, however, take the wide excursion to which I have adverted, I am under the necessity, as I said before, of referring to succeeding chapters, where the facts are discussed at large. For it is in experimental facts alone that all the strength of confirmation lies, and of the assistance of these I should be virtually destitute if I derived it only from those facts that preface the present chapter. I dare not, however, raise an edifice on principles educed only from a few recorded phenomena. Where a lofty superstructure is to be raised, a broad foundation must be laid. The mere powers of genius, unaided by facts, are altogether unequal to raise the edifice of true philosophy, and if they attempt to build it is only upon a basis of air. The Omniscient appears to have plucked the wings from the Mercuries of our planet, lest in disorderly multitudes they should roam at large in the highest regions of our atmosphere, till they lost their breath, and died of distention; and lest some should wish, with the daring of Icarus, to soar to the precincts of the sun, and to be scorched with its rays; that they might vaunt after their fall how very near they had been to a heaven that is foreign to their nature, and that at the expense of their wings, they had brought down Promethean fire, and drank the draught of the superior aura. No other wings (*talaria*) therefore are

allowed to the geniuses of the present age than such as are borrowed from experience.

163. *As both the blood and the vessels are of a threefold order, so also is every texture which is formed by the vessels ; as for instance, the glands, which are the receptacles of the secretions, and the ducts of the excretions ; for they are compound, more simple, and most simple ; and according to the order to which they belong, they are called either glands, vesicles, or pores ; one of which is compounded of the other, and one is divided into the other.* The divisions and definitions of the glands, as given by different authors, have been somewhat numerous. As to their *division*, most generally they are divided into conglobate and conglomerate. According to Heister, the conglobate are simple, consisting of one spheroidal corpuscle, distinct, and enclosed within its own diminutive proper membrane. The conglomerate, which are also called compound, are, according to Nuck, those which, constituting a congeries of smaller glands, are enclosed in one common tunic. Each of these glands emits a small excretory vessel, composing a canal, by which its liquor flows out of it into some observable cavity within the body, or else goes out of the body altogether. They are nothing but a tissue of most minute vessels composed of the finest arteries, terminating in two kinds of small vessels, one venous, or admitting venous blood, and the other excretory. As to the *definition* of the glands, they are defined by some as globose, soft, lax, spongy parts, as parenchyma, or as fungous flesh ; by others, as a congeries of vessels enclosed within their own proper membrane ; by others they are called glands, on account of the fleshy substance peculiar to them, that is, on account of their peculiar form, or their singular external appearance. Similar corpuscles, in a preternatural state, are frequently denominated by Malpighi, diseased tubercles, atheromata, steatomata, grandines, &c. And since they nowhere agree either in texture, situation, or use, a dispute has arisen, whether everything is to be called glandular which in any part of any viscus or viscera represents a vascular and vesicular congeries and compages. And again, it has been questioned whether this dispute be about words, or whether it be about a matter of fact.

164. But if we distribute into orders the vascular and vesi-



cular tissues as we do the blood and its vessels, and if we contemplate their degrees and origins either in a twofold or threefold relation : and if, thus discriminating between their natures, we give them appropriate names, then will the definitions of most authors agree, taking them in their broad sense, together with their deduction and description, and the foregoing various opinions will be found to harmonize in one, as founded upon one and the same common notion (n. 10). A gland is a coacervation of blood-vessels of a threefold order, consequently of the arteries and veins of the red blood, of the purer blood, as also of fibres ; and as glands are mutually distinguished from each other by their origin and composition, so are they likewise by their appellation. Each congeries respectively is circumscribed by its own common membrane. Interiorly there are formed, (according to the complication or conglobation and conglomeration of the vessels,) hollows, and larger and smaller ducts, which receive, convey, drain off, bring back, as well as excrete the secreted juice, and thus perform all the stupendous operations which are found to take place in the chemistry of nature. If the smallest hollows, or those belonging to the first order, be called inmost recesses, or little fonts inaccessible to any reach of the external senses ; and if the little ducts of that order be called by their common appellation of pores, invisible commissures, little chinks [*rimulæ*], permeable lines, or otherwise ; then a compages of these, overlaid with their own proper membrane, can be called neither a vessel, nor a vesicle, nor a follicle, nor yet a gland, unless upon the principle of its belonging to a degree implied and not expressed, or in an analogous or eminent sense. Moreover a congeries, mucous ball [*mucus*] or glomule, of such primordial parts of a gland, circumscribed still further with another common membrane, begets another order, whose somewhat larger cavities, or little vessels receptory of secretions, may be called either minute vesicles, or follicles, or fountains, or receivers, or little cases of fluid, or by any other such name ; and their little ducts may be called passages [*commeatus*], or open inlets [*accessus hiulci*], fissures, or otherwise : then any conglobation or compages of these, enveloped with their own common membrane, cannot properly be called a gland, unless on the principle of its belonging to a

degree implied and not expressed, or by way of analogy. Again, the compages which results from these, namely, a larger glo-meration, or globe, whether it be of a loose, spongy, fungous, or else of a dense and compact texture, and whatever be its color, figure, magnitude, appearance, and garb, is nevertheless in the proper sense a gland. Its minor cavities are also properly vessels receptory of secretions, loculi, vesicles, follicles, cells; its larger cavities are receptacles, conduits, cysts, ventres, cisterns, caverns, fauces; their ducts are canals, siphons, fossulæ, infundibula, and so forth. The circumstance of their being larger or smaller does not alter the nomenclature. See n. 156.

Without, however, illustration by examples, we shall advance but slowly. Let us therefore take the case of the brain, which in the intricate conglobation of its simple and primitive substances is an exemplar and effigy of all the compositions and derivations to be found in the body, and hence also the effigy and exemplar of all the glands. A spherule of cortical or cineritious substance, composed of vascular threads of infinite minuteness, and endowed with recesses from which fibrules or permeable lines proceed, is not a gland except in an eminent sense. The spherules and porules of this kind are conglomerated into nuclei, nodes, or cerebellules, which in the Part treating on that subject we shall call cortical tori, and which, both in their smaller effigy and in their appearance, altogether resemble the cerebellum, such as it is in its larger effigy; and when overlaid with their own proper membrane, compose another degree of cortical spherules, which nevertheless cannot be called glands except by way of analogy. From these again, connected together in the form of a spiral, and discriminated into separate convolutions, all overlaid and bound together with a double or triple tunic or meninx, the brain is produced; and thus has the character of a great or principal gland, whose larger cavities are the lateral ventricles, the intermediate ventricle, and the aqueduct; its passages are the foramina, called the vulva and the anus; its excretory is the infundibulum, which in the human subject is, together with the pituitary gland, employed to discriminate the humors which flow into it. Not to mention innumerable other things, which most satisfactorily teach us the nature of the glands. Of these several degrees of glands, the cerebellum be-



longs to the second, because it is homogeneous to the second degree of glands, or to the cortical tori of the brain, with which it corresponds. In like manner the glands, which in the body are called conglobate, are in their composition glands of the second degree; the conglomerate being those of the third degree. From the foregoing remarks it now follows, that

165. *In a similar order are carried on the secretions from the small arteries into the above glands; as well as the excretions: likewise the commixtion of the secretions, and the reabsorption by the veins.* I have already been detained long enough by the consideration of these more universal topics; let us now proceed to the blood, properly so called, and to its circulation, which is the main object of the present Part.

166. *To the end that all these things may attain to their due effect, there is required a constant circulation of the sanguineous volumes; namely, a circulation of the red blood from the left side of the heart into the trunk of the aorta; from the trunk of the aorta into its branches; from its branches into the smallest vessels belonging to that order; from these smallest vessels into the smallest veins, as well as into the numerous hollows and receptacles for the secretions.* On these subjects, as no doubt has been entertained, I forbear making any comment. *This circulation is performed by successive propagations of an undulation, each of which takes place within an imperceptible moment of time: in consequence whereof there arises in every part of the permeated vessels that sensible elevation which is denominated the pulse.* What that is which produces the pulse or causes the salience of the artery, is a question which has been classed among the occult secrets of anatomical science, and the solution of which is a desideratum among the learned. Some there are who attribute it to the blood only, to its heat, its spirit, its fermentation. Others who attribute it to the fibres and brains. Others who attribute it to the tunics, particularly the muscular, the extension of which Galen was of opinion depended upon a pulsific faculty. Willis thought it depended upon the animal spirit. Vieussens solely on the impulse of the blood, which he considered to be endowed with an expansive force (n. 122.) There are those again who attribute it solely to the heart, and maintain that the arteries have nothing to do with it; while others attribute to

the heart and arteries equal shares in its production. Whatever be the cause or causes of the phenomenon, there has I think been no dispute that the effect produced is an elevation and throbbing of the artery, as perceived upon applying the finger. Vieussens says: "It is very evident that in that motion of the arteries which is properly called dilatation, their coats are stretched in every direction beyond their natural degree of tension" (n. 122). Leeuwenhoek states that this arterial tension is carried on even in the very minutest arteries; for that he "saw the circulation of the blood going on in the [capillary] vessels [of a tadpole], . . . not with an equable and continuous motion, but by most rapid and impulsive advances, which every now and then were observable." And again he says, that "in various places close to the extremity of the [caudal] fin [of an eel], he could discern an elevation or rising in the most minute blood-vessels, corresponding to the moment of each fresh impulse that the blood received from the heart" (n. 125).

167. That this elevation is not simultaneous but successive; that for instance it derives its first beginning from the heart and has its termination at the extreme ends of the smallest vessels, where it is continued into the minute veins, is a fact which admits of little controversy; for, as we have said, those protrusions have been actually seen, as also the small volumes and parts of the blood which were hurried to and fro; the increased rate of speed occasioned by the extension of the vessel; the intermissions which took place whenever there was any intermission in the motion of the heart; the states of inaction and quiescence which followed when the motions of the heart ceased; the successive and distinct translation of the volume from the venous sinuses into the auricles, and thence into the ventricles of the heart, which are succeeded by the arteries, these converting what is successively contiguous into what is successively continuous. Reason also is on the same side of the question; for were the elevation of the artery instantaneous or simultaneous, the artery would repress the blood as much as it compressed it; the blood would thus be coursing backward and forward, and there would be everywhere one general pulse; that is to say, one indiscriminate elevation imperceptible to the touch. He, therefore, who would doubt that the elevation of



the artery is successive, must revoke the evidence of sight, of touch, of microscopical observation, and of the reasonable laws which are educed from them.

168. The imperceptibility of the periods within which the undulation travels from the heart to the extreme ends of the arteries, does not supersede the fact of the existence of succession. Nor must we discard the idea of succession in the purer blood, because the undulation there is still more imperceptible; nor again in the spirituous fluid, because there, in its course through the fibrils, that fluid outruns, if possible, the speed of the will; communicating its impression simultaneously to the last stations and the first, as is manifest from the voluntary motions of the muscles. How rapid is the speed of this undulation in modulated air, how much more rapid in modified ether, and how almost instantaneous in the auras of the superior degree, is abundantly proved by the phenomena of the mundane system. In the superior auras, myriads of myriads of moments give birth to scarcely one moment in those ultimate forms of nature which are presented to the bodily eye. To deny to nature the possession of her distinct times and moments, because by reason of the dullness of our senses we cannot perceive them, is in fact to remove nature out of her sphere of operation, to bound her occult processes by the limits of sight, and to deprive the rational mind of all opportunity of exercising itself on the subject; for the only thing which in such a case it is in the power of the mind to do, is to observe the common or general effects which are perceptible to the senses, resulting from those operations of nature which are imperceptible, and from these to contemplate causes.

169. Now this elevation of the artery to which we have referred, we maintain to be an *undulation*; and since in this undulation both the law and the mode of the circulation are contained, it is worth while to enquire what this undulation is, of what kind it is, and whence is its origin. There is nothing in all nature which is not formed in motion, hence according to motion, and for motion; for the veriest state of nature is an active state, and therefore nature is defined to be an active force. According to this force are formed the substances of the mundane system, which are distributed into three species of

motion; namely, local or translatory, undulatory or modificatory, and axillary or central. Of these we are here treating only of the second species, namely, undulatory or modificatory motion.

This species is the mode of propagating local motion once begun, from one distance to another, and hence even to the remotest, without the translation of the volume or mass on which the first local motion was impressed. The progression of this kind of motion is perfectly unobstructed till it terminates in a certain species of *conatus*, which upon yielding or non-resisting bodies produces the same effect as if the very first motion itself were present.

But let us proceed to the investigation of the several particulars of this description.

170. "Undulation is the mode of propagating local motion once begun, from one distance to another, and hence even to the remotest," &c. This we may see exemplified in water and other liquids, which when disturbed by any percussion, when touched or moved by any living force, immediately from the disturbing point as from a centre evolve sinuations and spreading circles; whence this species of motion has justly obtained the name of *undulation*. We may see it exemplified in air; for when a string is made to vibrate, such as that of a harp; when a membrane is struck, such as the parchment of a drum; when a volume is propelled, as when air is blown through a horn, a pipe, or the trachea; immediately we find that from the first disturbing point, as from its centre or axis, the air is rolled forward to a distance,—a motion which is properly called *modulation*. We may see it exemplified in the ether; which, as soon as the subtile sulphurous halitus are excited by the flame and fire of a hearth or of a candle, immediately darts from the corpuscles which are adequate and proper to that atmosphere, into the space occupied by its own universe, exhibiting the motion which is properly called *modification*; whence this species of undulatory motion is also called modificatory motion. The origins of all these motions are living; they are motions in their actuality, impetuses, and impulses: so is also that general modification, which by the



organ of sight is recognized as illumination, and which probably arises from the animatory motion or animation of the solar ocean, or of some star, continually exciting itself into an undulating motion, and which effuses itself beyond the bounds of its own proper universe. In the aura which is purer than our ether, the nature of undulating motion is exemplified still more perfectly, and is there called the analogue of a mode, or a variation of limits. In the supreme aura, the undulatory motion is performed in a manner still more indefinite, where there prevails not a mode such as in the last case, but a mode in the eminent sense of the term, or a natural principle of modificatory activity, which, for want of a better word, has by some been called mutation.

With regard to the quality of undulation, we observe, that it is of the same kind in the microcosm or little animal world, as it is in the macrocosm or the world at large; so that it appears as if one was ordained in relation to the other, and that one existed for the sake of the other, with this difference, that the fluids of the animal world are properly speaking living and animate. In these living and animate fluids there are species of motion similar in nature and in number to those which exist in the macrocosm. Of these species of motion in the microcosm, the undulatory, begun by a local motion similar to that in the macrocosm, is propagated from one distance to another without a translation of the same wave or volume sent forth. Thus the blood, when put into its first motion by the wave injected into the artery from the heart, continues to creep forward and roll through the arteries, which is the occasion of their throbbing and pulsation. The mode of motion is here as in other liquids, undulation; the point which elevates itself is the pulse, and the continuity of the motion is the circulation. It is by a corresponding species of motion that the spirituous fluid is carried through all the fibrils by means of the animation of the cerebrum and cerebellum. With regard to the middle or purer blood, in order that this also may circulate through its vessels, the lungs are called into aid by the brains, and thus by means of their respiration, which is constant and synchronous with the undulations of the purer blood, they procure for it a similar mode of action. On this subject I shall speak at large in ano-

ther part of my work. From these various considerations it follows, that in the animal body there are three general fountains of undulatory motion, namely, the brains, the lungs, and the heart.

In addition to these general causes of undulation and modification, there are also others which are particular, which refer to their common motion as to their entire motion, in the same manner as colors have reference to illumination, which therefore is seen and is considered to contain within itself all the various colorations as so many particular modifications (n. 85—89). The case is the same with the violin, which does not give out any distinct tone, unless it be in a state of general tremor, which is acquired by the co-tremulous body to which the strings are affixed; just as also in the organ of hearing, all the neighboring parts of the os petrosum, the cranium, &c., are put into a state of contremiscence with the ear, which is as it were sculptured out in them. Unless therefore there were in the heart the origin of some common undulation of the blood, the particular undulations, or those of the several arterial branches, could not subsist. Hence if at any given point of an artery a little wave were sent into it either by inflation or by means of a siphon, it would run onward immediately to the very ends of the twigs or offsets, in the same manner as it does from the heart into all the ramifications generally. These ramifications then everywhere resemble one continued heart, and argue its presence. What is general, therefore, is first required, in order that what is particular may live; and conversely, what is particular and similar to the general is required, in order that the general may live, and with a distinct life.

From the foregoing considerations it is clear, that undulation is of a multifold origin, nature, composition, and hence of a multifold order and appellation. It is of a multifold *origin*, being according to the various substances which are so modified. It is of a multifold *nature*, being according to the perfections of these substances. It is of a multifold *composition*, being according as the substances are pure and simple. It is of a multifold *order*, being according as the substances are more universal and superior. It is of a multifold *appellation*, being called, for instance, in water undulation, in air modulation, in



ether modification ; after this it is called, not a mode, but the analogue of a mode, a mode in the eminent sense of the term, a first principle, a mutation. In the blood it is a systole and diastole, or in general a circulation ; in the purer blood, it is, permit me to say, a respiration ; in the spirituous fluid it is an animation. The intermediate modifications are according to the organs which modify, or which are themselves modified, such as those of the touch, taste, smell, hearing, sight ; and the superior modifications are according to the internal organization, such as those of imagination, and so forth. In like manner in continuous or solid substances there are their proper modifications, such as oscillation, vibration, tremulation ; insensible contremiscence, modification, &c. But the origin and progression of all these have reference to the same law, namely, that motion once begun is propagated or forwarded from one distance to another, even to the remotest, without the translation of the volume of the parts on which the first local motion was impressed.

Now I say, that in continuous or solid substances, in a word, in masses, the manner of the propagation of motion is similar to that which prevails in contiguous substances, fluids, or volumes, or even in substances of a softer character, and which are intermediate between solids and fluids, such as crassamenta, glutinous, waxy substances, membranes and medullæ, or those which are included within the science of sarcology. For soft and solid substances regard the fluids as the causes of their existence and subsistence, wherefore in these respects they emulate the nature of fluids ; for all things are formed and completed in motion, according to motion, and with a view to motion, as was stated at the commencement of this article upon undulation. Upon this account it is that oscillation, vibration, tremulation, or undulation, does not cease to be modulation and modification analogically, or in a preëminent sense. For the exaltation of forces and powers does not deprive them of their mode, or prevent their being in themselves similar to what they were before, but elevates their nature, and causes them to ascend out of the perceptibility of one sense, into the region of its imperceptibility, or to the perceptibility of another sense. Nor does the circumstance of a force and power appearing to be one thing in fluids and another in solids, one thing in

the substances of the mundane system and another in similar correlative substances of the animal kingdom, make any alteration in its essence. Let us now however pass on to the next part of our description.

171. "The progression of this kind of motion is perfectly unobstructed;" as we see in fluids, in which it advances by sinuous creeping motions, by circles, orbs, perpetual spirals, by forms of nature most perfect, simple, and peculiar to themselves. In solids the motion progresses in a similar kind of manner; but since, in consequence of the obstacle presented by that continuity of substance into which the particles are disposed and in which they cohere, it cannot progress in a manner actually the same, the motion is effected by means of continuous contact, through the medium of certain interfluent aqueous elements or auras. That the progression of this kind of motion is perfectly unobstructed, appears from the effect produced; as for instance from its presence in one extremity of a substance while it is yet in the other extremity, from its power of transferring itself thither, and indeed from its continuous progression from one circle to another, or through the heliacal curve to which nature has committed the highest execution of her forces. But let us speak by way of example apparent to the senses; as for instance, this motion progresses from a single violin to the ear of a person who may yet be at a considerable distance; from the slightest spark, through a distance of many thousand paces, to the pupil of the eye; from a solitary star, or from the sun, through the regions of the surrounding universe; from a grain of dust dropping from the ceiling to the floor, through the entire story of the building; from the grating of a small file, through the whole of the osseous, cartilaginous, and fluid system of the body; from a tuning fork, through a great beam, to the teeth of a bystander which are made to bite its further extremity; from a small revolving wheel, through a spacious house, a palace, a court, a mountain, which are all clearly put into a state of contremiscence with it; from the spot in which an earthquake takes place, through a distance of a hundred miles and more: through a solitary filament into an entire continuous expanse, and thence through an intermediate little stamen into another continuous expanse, and so on. Nay, with so great a might does it act,



that were we to use somewhat ruder illustrations, we should say, that while progressing slowly along a rope, nothing could possibly prevent it from reaching its extremity ; and that were we to attempt to force the waving into a rectilinear motion, not even the strength of elephants would suffice. If this be the case with substances of an inferior degree in nature, why may it not be so with those continuous and contiguous substances of the superior degree, in which the same mode reigns to an incredible extent more perfectly, presently, and potentially ? Why may it not be so, more particularly when we consider that the progression of the motion is perfectly unobstructed, and that the direction of its course or spiral figure is most highly adapted to nature ? The third clause of our description of undulatory motion is,

171 $\frac{1}{2}$ . “That this motion terminates in a certain species of conatus.” It passes for instance from a local motion by means of an undulation or modification into a conatus, which is both the end and internal beginning of every motion ; for motion is defined to be a perpetual conatus, on the extinction of which motion itself is extinguished. It is resistance which stops the progression of local motion, and converts it into conatus, because this motion persists until it is resisted, since the veriest state of nature is a state of motion. Motion is in its own essence, when its force is in its actuality active ; its progression is into what is indefinite, unless there be resistances by which it is restrained, and from which ultimately a state of equilibrium or rest arises. This is evident even to the senses, because according to the last clause of our description,

“Conatus produces upon yielding or non-resisting bodies the same effect as if the very first motion itself were present.” As for instance when a bow is bent which is in the continual conatus of unbending, no sooner is the resistance removed than it recoils in proportion to the degree in which it acts freely. In the same manner also, when air once modulated reaches the ear, and modified ether reaches the eye, they produce upon these organs an effect similar to that which would have been produced had the first motion been present ; for in their yielding fibrils, little membranes and retinas, motion commences as it were afresh, and is dispersed through the softer stamina and

their fluids even into the brain. On this subject, however, we shall speak more at large when we come to treat of these particular structures.

In the meantime we observe, 1st. That no other doctrine comprehends such a multitude of scientific laws, as this of undulatory motion; for to this doctrine belong the laws of incidence, reflection, refraction, optics, music, physics, physiology, &c., with others that might be mentioned. We observe, 2nd. That undulation or modification is excited by hard and firm corpuscles, put into a certain motion, and is thence transferred into some fluid: it is excited, for example, by strings, sonorous membranes, and other bodies which are more particularly tremulous, and is thence transferred into the air; it is excited by most subtile exhalations, and is thence transferred into the ether; it is excited by any corpuscule thrown into the water, and is transferred into the rest of that element in a manner not unlike the one we have referred to in our remarks upon heat and color (n. 82, 87, 88). It is excited moreover by fluids, and is thence transferred into cohering substances, in the same manner as it is by the tone of one string, through certain media to other concordant strings, and from the ears into the organs of hearing and sight. 3rd. We observe that undulation increases according to the degree of elasticity in the parts of a body, in the volume of the parts, and in the mass; that in heavy bodies it decreases according to their degree of *vis inertię*. 4th. We observe that in one volume it is produced from a thousand centres simultaneously and successively; that when thus produced, it subsists, is represented, is prolonged, as is evident from modulation in the aërial atmosphere, from modification in the ethereal atmosphere, (as exemplified in the organs of sight and hearing,) and also from undulation in water. Hence it is possible for there to be a manifold, simultaneous, and successive series of undulations, one in another; and consequently for one and the same part to be simultaneously in any circumference, in any radius, in any point of a circumference and radius, and likewise in as many centres. 5th. We observe that this undulation can exist in its integrity in any volume, however moved or translated from one place to another the volume may be. 6th. That infinite particular modifications, as so many



units, ratios, or harmonies, can exist in, and can enter into, one common and universal modification ; there can be for instance, indefinite series of one degree above those of another. 7th. That the relation of undulation to a body which is in a state of translatory motion, is just the same as if the body were at rest. In one word, there is nothing in all nature more wonderful than undulation ; nothing which includes a greater multiplicity of laws ; nothing which is more worthy our consideration, or of more importance in physical and physiological studies. It is in fact the one great subject which demands our attention in the science of the animal economy ; so that to expound this science without any knowledge of this mode of motion, is like attempting to explain geometry without lines and figures, or the art of navigation without the use of the rudder and the compass. For nature, which is an active force, has transcribed its life into the three above mentioned species of motion, and particularly into that of undulatory or modificatory motion. The whole animal organism, nay, all the substances of the mundane system, it has ordained and formed in accordance with this motion. This is the reason therefore for which I have so long detained the reader in explaining its laws, and although, on the present occasion, I have been able to state only a very few of the principles of this doctrine, yet when I come to speak of the external and internal organs, he will meet with an entire Part on this subject.

172. Let us now revert to the subject of the blood, in which we discover a similar form or image of undulation. For we see, 1st, that undulation commences from the wave sent from the heart. 2nd. That it is propagated through the continuous arteries even to the smallest twigs, and this, with facility. 3rd. That it terminates in a conatus. 4th. That from this state of conatus it gives out an effect similar to that which would have been produced had the first motion itself been present, and by progressing through the little arteries rolls its streamlet through the various ramifications into the veins, where it meets with its outlet. This undulation through the arteries would still continue even were no outlet for the blood supplied by the veins, as we see in the case of muscular fibres when constricted, or otherwise obstructed ; for then just so much of the wave

regurgitates as had been insinuated into the vessel,—a fact exemplified in the rebound of a wave in water. 5th. That there is a similar propagation of undulation from any one point of an artery taken *ad libitum*, so that at whatever point liquid be injected, it glides through the various ramifications even to their extremities, in like manner as if it had been injected from the heart. 6th. That the undulation ceases at the extremities where the artery ceases and the vein begins, because the innermost tunic of the artery becomes the outermost of the vein, and the undulation proceeding along a canal whose diameter is gradually increasing, becomes extinguished, and does not pass into the enclosed volume, inasmuch as the vein is not surrounded with a tunic like that of the artery, determining and collecting the forces and reducing them to one common or general action (n. 187, 188, 189). 7th. That the artery is formed as it is solely in relation to the undulation of its fluid, in like manner as the ear is formed to the modulation of the air, and the eye to the modification of the ether. The tunics of the artery are thus formed in relation to the blood it contains, and the blood in relation to the tunics which contain it, so that the two act as one cause of determination (n. 134). In the same manner also the medullary fibre of the brain and the nervous fibre of the body have each a similar relation to the fluid they contain. 8th. Hence it is according to the determinations of the several vessels and fibres, which are only particular directions of one common undulation or modification, that all the vital effects take place in such wonderful correspondence with the chemical, physical and physiological operations of the animal kingdom. 9th. Thus also it is that all the opinions which have hitherto been entertained on the causes of the circulation of the blood, concur in one (n. 10), as for instance, the opinion of Galen, which is the oldest, that the cause of the circulation is a pulsific force; the opinion of Vieussens that it is an impulse of the blood endued with an expansive force; the opinion of others that it is the muscular tunic; others that it is the heart; the opinion of Willis, that it is a spirit, though it may be doubtful whether by this he means the spirit that is in the fibres of the muscular tunic, or that which is in the blood and which Harvey denominates vital. They, however, who



attribute the circulation to a certain fermentation in the blood, do not appear to have founded their hypothesis upon any general idea adequate to the phenomena presented.

173. *This little wave having received its first impulse from the heart, is afterwards moved forward by the whole arterial system.* This is sufficiently proved by the preceding article; since, as we have said, the artery is formed relatively to the undulation of its fluid; for as the ear is formed with a view to the modulation of the air, and the eye to the modification of the ether, so is the tunic of the blood-vessel formed in relation to the blood, and the blood in relation to the tunic, and thus the two act as one and the same cause of determination, as we may more particularly see on considering that a liquid injected at any part of an opened artery, is conveyed away to its little branches in like manner as if it had been injected into the artery from the heart. Hence every point in an artery has relation to the point which precedes it as to somewhat of the heart, because from that point as well as from the heart the wave has been propagated. Thus the whole of the arterial system constitutes as it were one single heart continued and elongated to the ultimate vessels. On the mode however in which the muscular tunic coöperates, see n. 182.

174. *Presenting a rapid current, which acquires an accelerated velocity.* In other words, the flux of blood through the smallest vessels is expeditious, and indeed more so than through the larger vessels. With respect to the *first proposition*, or that the blood flows in a rapid current through the smallest vessels; that the several resistances offer no impediment, the several frictions no retardation, nor the various angles, inflections and circuitous directions, any check to the course of the blood, it may be observed that this fact is proved by the following considerations: 1st. That every muscle in every part of the body, whatever be its mass or quantity of flesh, can turn pale in an instant, be indurated, compressed and convulsed; for it is a texture and collation of most minute arteries, from which the blood pours itself forth the instant that the mind sounds a retreat. Yet assuredly the sanguineous liquor would lodge in the little pores and sinuosities which are so highly contorted and complicated, if resistance increased in proportion as the dia-

meter of the vessel decreased. 2nd. It is proved to the evidence of the senses, by the blood in the arterial filaments, as in worms, particularly in the fins and tails of fishes, the crests of birds, wings of bats, and other appendices of living creatures, as seen through the microscope; for the blood in those members considerably quickens its speed, and this, as Leeuwenhoek says, “by most rapid and impulsive advances” (n. 125). 3rd. It is proved by the face, also the skin, and every extreme part of the body where the plexiform network of the vessels abounds, all of which parts turn crimson or pale the moment any change takes place in the feelings. 4th. The blood, upon any sudden occasion of terror, flies immediately from the arteries to the veins, as though there were nothing to restrain the flight of the timid fluid, or to oppose to it the slightest obstacle. 5th. At other times, as much blood as is forced from the heart by every systole, passes for the most part through the larger and smaller vessels into the venous asylums, and through the secretory vessels into various little caverns and cavities. The contrary would be the case were the impetus of the blood retarded, the resistance increased, and the rate of speed diminished, as the vessels decreased, became divided, and inflected. 6th. In animalcula and insects, we see that the blood, whether of a golden or silvery hue, circulates through the arterial web without friction or renitency, yet notwithstanding, as Malpighi and Leeuwenhoek have both observed, passes through innumerable circuits, tortuous plexuses, and intricate meshes. For the great artery of these animals is scarcely equal to a capillary vessel of the human frame, and a whole muscle is scarcely as large as a minute fibre in the human body, and yet there are the most rapid impetuses in their system, as indeed may be seen from the quick vibrations of their wings, feet, and other little members of their bodies. 7th. To these arguments may be added the phenomena presented by revulsion and derivation. 8th. Reason likewise urges, from a variety of experimental facts, that were any even imperceptible reaction exercised by the smallest vessel, yet in consequence of the combined efforts of such an immense number, the heart and larger arteries would in their turn have to exercise a correlative action to an immense degree, or in vain would they attempt to forward the blood into



the veins; as indeed we find to be the case when the capillary arteries are obstructed by clotty, viscid, gelatinous substances, and the blood is transmitted only through the larger vessels, as happens in fevers, and most other diseases originating from contaminated blood. For were even the slightest friction to retard the minutest globule, we should find that, unable to act, it would everywhere be loitering and stopping on the road, and the unanimity between itself and the tunic being thus destroyed, it would never find its way through the artery. Thus instead of a continuous transflux of the current, mere obstruction and inaction would arise, so that death would supervene and forestall disease. To guard against accidents of this kind, nature is ever aspiring to her own spontaneity, nor does she find it except in her purer kingdom, while proceeding to which, she disperses all obstacles, facilitates all her paths, and accommodates one to another her various substances. 9th. Nor does the science of physics invalidate or impugn this position of the tendency of the blood to glide rapidly through the smallest vessels, inasmuch as we shall see in the sequel (n. 236) that more blood is contained in the minute vessels than in the trunks, and that the membrane of a vessel possesses the highest degree of adaptation to the blood it contains (n. 134); that thus it reacts as much as it is acted upon, and is ever propelling its own little volume in the direction of the arterial extremities.

175. In regard to the *second* part of the *proposition*, in which it is stated that the blood proceeds with accelerated velocity, or that through the smaller vessels before mentioned its current is more expeditious than through the larger, we observe that this fact may in some measure be inferred from the figure of the arteries, inasmuch as they are conical. Thus Morgagni observes, addressing Manget: "You might have known from the anatomy of the ostrich, as given by the experienced Vallisnerius, that where the great artery of this animal for four inches and a half gives off no branches, it was clearly seen by . . . J. Dominicus Santorinus . . . and Bernardus Zen-drinus, to be, not cylindrical, but conical" (n. 119). We must thus compare them with pipes or conduits, through which the water as it flows accelerates its course at every point of its progression, to compensate for which it is requisite that the dia-

meter of the pipe should be lessened, the previous greater size of the vessel and of the volume it contained being compensated by the increased celerity of the volume. 2nd. Leeuwenhoek, who everywhere adds to his statements the testimony of fact, maintains his own opinion in opposition to that of others who differed from him, when, as quoted by Verheyen, he remarks, in regard to the smaller arteries [or to certain tubes constructed to represent them], "that unless collectively they are of a calibre not inferior to that of the larger tube, the liquid must run through them more rapidly than through the larger" (n. 116).

But inasmuch as the increments in the degrees of the velocity of the blood, in its passage through the larger and smaller vessels, are not easily observable,—since all the moments, taken collectively, during which the blood is running from the heart through the intermediate channels to the extremities of the system, would scarcely amount to a single moment perceptible to our senses (n. 168),—hence we must have recourse to reason, which by comparing the state of the blood with that of the blood-vessels, and drawing its inference, is enabled to throw a clearer light upon the subject. The arguments of the induction will be as follow: 1st. That in the somewhat larger vessels the blood is surrounded by a serosity, whose inherent sluggishness retards the *nisus* of the quick blood; in proportion, however, as the blood progresses, it disperses the various hindrances to its course, and purifies itself from everything which tends either to pollute its dwelling or repress its velocity. Baglivi observes, that the lines at the centre or axis of the vessel to which the blood directs its current, appear to be in a greater rapidity of motion (n. 124). 2nd. The blood, during its passage into its own congenial region of minuter vessels, becomes gradually purer, and can both act and be acted upon according to the degree of its pliancy and elasticity; it can be moulded into an oval form, and can be divided into more supple and agile spherules; moreover it meets with little cylindrical canals, and with a highly levi-gated surface, as the author above referred to has discovered by his microscope. It is to this sphere that the blood is constantly aspiring, in order that it may be here left as it were to itself, and to the enjoyment of its own nature. 3rd. A little vessel



invested with circular fibres, receives a particle or a little volume into a state of perfect embrace, or acts upon it with its full force ; presses upon it in more than a thousand points, and imprints upon it as many kisses ; when in a larger vessel it could not so much as be touched. Such a particle or little volume of the blood, therefore, suffers itself most obsequiously to be wafted away at a rapid rate into the extremities of the vessels, and is propelled by a force of the tunic, which the particle, by reason of its elastic and yielding nature, cannot resist ; for each has the greatest possible conformation to the other. 4th. Thus at every fresh point in advance a fresh pressure is superadded, while the degree of resistance offered by the blood becomes itself gradually less. Hence arises a ratio of velocity not unlike that which belongs to solids or fluids when falling or rising through their several atmospheres to their centre of gravity. This is illustrated by the preceding article, in which it is stated that the undulatory motion of the blood rolls with the most perfect facility to the arterial extremities, directs its course to the regions of the purer blood, and multiplies its rate of velocity according to its degree. The subsequent article likewise shews that there is a general pressure of the arteries in the direction of the ramifications, or that there is as it were a perpetual conatus exercised by the tunic upon the enclosed volume of blood ; whence the undulatory progressive motion is continually living in its own perpetual cause. This being the fact, I have no hesitation in admitting this additional proposition, that blood flows from the heart in a rapid current and with an increasing celerity ; or according to the terms of our theorem, that the circulation is carried on, not only at a rapid rate, but even with accelerated velocity. I am aware that on this point there are those who are of a contrary opinion, with whose approbation therefore I shall not be favored : but why should I be so desirous of the good opinion of others, as to seek to please them at the expense of truth.

176. *In the vessels of the second order, the transflux of the wave is still more rapid and more spontaneous : in the vessels of the first order, or in the fibres, the degree of velocity and spontaneity is indefinite and immense.* For according to our rule, everything is still more perfect in the superior degree, so perfect in-

deed as to be considered as it were the analogue, the eminent and unassignable correspondent, of the similar qualities, powers, faculties, and modes of the inferior degrees. For in things belonging to the superior degree, there is the highest elasticity, compressibility, and pliability (n. 100, 101, 102). There is an absolute correspondence of the vessel to its fluid, its passivity being adapted to the nature of the activity of the agent, so that the subject, the force, and the cause of the determination are altogether one. (n. 134—137, *seqq.*) A fluid of this kind therefore requires as its vehicles only such vessels as those of the medullary fibres in the brains, which are so soft to the touch as almost to be fluid, and consequently mere ways of determination, being in such unanimity and agreement with the fluid they contain, that no impression communicated in any part is lost at the extremities; while at the very same moment, or even instant as it were, the ultimate impression is answering to the primary, or the effect following the cause.

177. *The action of the fibres does not depend on the action of the great or single heart, but on the actions of an infinite number of corcula, or as it were little hearts, namely, the spherules of the cortical and cineritious substance, which are prefixed to each fibre in the brains and their two medullæ.* In the anatomy of the brain it will be seen that the cortical spherules are perpetually animating, or exercising an animatory motion; that they emulate the systole and diastole of the heart; that by this perpetual animation they cause the brains alternately to expand and collapse; that thus it is they divide the blood, exclude the new spirituous fluid, transfuse it into the fibres, nerves, and vessels; are in a state of conatus, and excite motion; will and perform actions; vivify, renovate, and conform both the whole and the part; continue the woof inchoated in the egg; regard the body as an appendage; the action of the body as the same with their will; and the motions of the body as the same with their cause and principle. All these results, however, would not take place, unless spherules were severally prefixed to the fibres, and unless the fibres thus derived their animation from the force which was proper to these spherules, and did not depend for it upon the large heart; or, in other words, unless they were under the auspices of the universal circulation.



178. *In order to direct and promote the circulation, there is required a certain general pressure, or equilibrium of pressure, of all the arteries, tending from the heart in the direction of the arterial extremities.* In order that the undulation, after it is once begun, may progress continuously and as it were spontaneously from point to point, from the wider to all the narrower vessels of the arterial system, it is absolutely requisite that there should be a certain general pressure exercised by the whole of this system, consisting as it were of a conatus and joint nisus of the parts, and tending in the direction in which the wave is to be propagated. That there is such a general pressure exercising this conatus and joint nisus, as well as directing, promoting, and urging onward the undulation, the results of experiment seem to leave no doubt. 1. "We fastened a dog to a table," says Vieussens, "[and] laid open its abdomen. . . . We . . . secured the descending trunk of the aorta a little below the diaphragm, and a little above its iliac branches. We then opened the part of the vessel between the two ligatures with a scalpel, and . . . introduced [a] little tube that had been in warm water into the cavity of the artery. . . We tightly tied the artery down upon the tube with two ligatures, so that the aperture in it was included between them. We proceeded thus far with as much care as possible, . . . and we now found, manifestly both to sight and touch, that when we untied the two first ligatures, the artery pulsated almost as strongly below the tube as above it." 2. "We then plugged the cavity of the tube itself with a small piece of sponge, and . . . inserted the . . . tube . . . into the cavity [of the artery], but this time we did not tie down the artery upon the tube. . . . We then untied the two ligatures that had been placed on the artery; yet although this was done, . . . there was no pulsation below the tube." 3. "We tied a dog's crural artery with two ligatures and divided it across midway between them, and we then tied the crural vein. When this was done, the artery sensibly collapsed below the inferior ligature, while on the other hand the vein swelled up in the corresponding situation. Yet every one must see that the heart's impulse was intercepted, while the blood was moving in the above vessels below the ligatures." 4. "A strong dog was fastened to the table, its abdomen laid open, and both its iliac

arteries tied. . . . We [also] . . . tied the ascending trunk of the aorta, and the other vessels of the heart near its base. . . . The motion of the heart thus entirely intercepted, we made a slight incision into the descending trunk of the aorta, when the blood spirted from its cavity with great force, and as it were in distinct jets" (n. 122). 5. Boerhaave observes, that "if an artery be laid bare, and tied with a ligature, it swells and beats between the ligature and the heart ; but becomes flaccid between the ligature and the extremities" (n. 126). 6. The same author observes, that "an artery may be expanded by the distending impetus of the blood ; yet this impetus ceasing, it has the power of spontaneously regaining its former calibre. For if the finger be thrust therein, it forcibly compresses the same, and contracts of its own accord as soon as the finger is withdrawn. In a living animal the artery appears full, but it is found small and nearly empty in a dead human body, even where no blood has been lost previously to dissolution. The arteries resist inflation, forcibly repelling the air that is driven in ; and in contracting, they rest at the point of the least diameter." (*Ibid.*)

When therefore we consider, 1. that the artery pulsates after a pervious tube is inserted into it : 2. that after the tube has been plugged by a sponge it does not pulsate : 3. that below the ligature the artery collapses : 4. that when the motion of the heart was intercepted, and an incision made considerably below the ligature, the blood was projected from the artery in distinct jets : 5. that the artery pressed upon the finger when thrust into it ; that when the finger was removed the artery spontaneously contracted ; that in a dead body it is empty ; and that when collapsed to its smallest diameter it is at rest : 6. that liquor anywhere injected into the artery is, without receiving any impulse from the heart, propelled into the veins, which distend when the heart is flaccid : 7. that the blood flows in a continuous stream, not at distinct strokes, nor by alternations according to the beats of the pulse, as is clear from incisions made into the artery : 8. that the artery has no valves ; not to mention many other things worthy of remark :—when all these things are considered, what do they tend to shew, but that there is a general pressure of the arteries toward their extreme ramifica-



tions; that there is a unanimous conatus exercised by the several arterial points in propelling the blood from the arteries into the veins; or that there is a certain continuous agent extending throughout the whole arterial system, and of the same nature with that which appears in the heart, but which in the heart is not continuous, but distinguished into contiguous intervals: consequently that the arteries are exercising the same office with that of the heart itself; that taken collectively they form as it were one general heart continued down to the veins, by which means the several forces are so ordained, that effects never fail in answering to their cause; but throughout the arterial system, there is, so to speak, a continuous cause of effects, and at the same time a continuous effect of causes. This I call therefore a *general equilibrium of pressure*; inasmuch as in order that the circulation may subsist and continue in its integrity, the arteries require to be kept expanded to a certain level by means of the little wave injected by the heart in distinct moments or alternations.

179. Thus we see the reason of the proposition in n. 173, 174, or for which the wave, having received its first impulse from the heart, is propelled by the whole arterial system to its ultimate outlet, and this, at a rapid rate and with an accelerated velocity. For at every single point in the line of progression a new impelling force is superadded, and hence there arises a velocity which increases in a duplicate ratio, according to the rule observed by solids or fluids, when descending or ascending through their atmospheres to the centre of gravity. The lightest and purest atmosphere which belongs to the blood, and toward which the sanguineous current is ever tending, is the region of minuter vessels. This atmosphere is heavier in the trunks from which the branches proceed, and is heaviest in the heart. Thus in arriving at the lighter or purer atmosphere, the blood, properly speaking, does not *descend* nor is *carried downward* from the heart, but *ascends* and is *carried upward*; and in order that it may more easily rise thither, it purifies itself as it goes, throwing aside all the impediments which occur in its way, and which are finally carried off into the recipient secretory vessels.

180. *Since without a pressure exercised by the whole arterial*

*system, there is no circulation; as indeed without a circulation no general pressure can exist or subsist.* 1. A general pressure drives all the blood into the extremities, and this, even to the degree of fatal exinanition. The wave propelled into the arteries by the heart, restores and maintains the equilibrium. Thus the existence of one demands the existence of the other. 2. The general pressure has a tendency to extinguish the life of the artery, by the entire expulsion of the blood; the wave propelled into the arteries restores their life: so that there is a perpetual loss and recovery of equilibrium, a perpetual struggle as it were between life and death, the victory alternately siding with each; and thus the existence of one implies the existence of the other. When the stern necessity of death at last arrives, then the general pressure is victor, and the circulation ceases. Thus when all the blood has been expelled from the arteries into the veins, it immediately directs its course to the right auricle of the heart, in order that there the heart may resuscitate life. 3. The quantity of blood infused into the arteries exactly corresponds to the quantity expressed from them by means of the general pressure. In this manner again the existence of one implies the existence of the other. 4. Hence the general pressure and the circulation are two distinct things. The general pressure originates no pulse, this being occasioned by the circulation alone.

181. As therefore the existence of one implies the existence of the other, so also does the nature of the one accommodate itself to the nature of the other. Such, for instance, as is the general pressure, such is the circulation, and such the pulse arising from the circulation. The pressure varies according to the various changes or affections experienced by the brain or the body in general. The circulation varies in a similar manner. Thus the pressure is of one kind in a state of anger, animosity, rage, fever. It is of another kind in a state of fear, terror, shame, hope, impatience, melancholy, consumption, ague, &c. It is of one kind when the fibre is devoid of its proper spirit and powerless; of another kind when it is in a state of animation, and vigorously propelling its enclosed little wave. It is of one kind when the fibre is irritated by some ungovernable stimulus; of another when it is affected with none, or only gently



and mildly. It is of one kind when the blood with its sluggish serum obstructs the capillary tubes and refuses to flow ; of another when it speeds its course with life and alacrity, and tries to forestall the nisus of the compressing artery. It is of one kind when the arteries turgescence beyond their due limit with a large abundance of their enclosed fluid ; of another when they are compressed within their due bounds by reason of its scantiness. In fine, this general equilibrium of pressure, as confined within the limits of its own maximum and minimum, is subject to changes every month, week, day, hour, nay, every moment, according to the changing states of the brain and of the body. Conformably to this state of pressure it is, that all the chemical, physical, and mechanical operations of the blood are carried on ; so that this general equilibrium is as it were the basis of the whole animal economy. The knowledge of its laws and nature is the cardinal point of all the sciences of angiology, adenology, and myology, comprised in the living animal ; for the life of the body consists in the existence and regulation of the general pressure and circulation.

182. *In order to promote this general pressure and circulation in the vessels, there is required a muscular tunic, provided with a multifold series of motive rings, and continued from the muscle of the heart to the capillary vessels.* “The third tunic, . . .” says Verheyen, “is muscular or fibrous, consisting of annular fibres set thickly together. These fleshy and motive fibres surrounding the arterial tube, are not disposed in a thin and single series, as in the venous coat, but aggregated and superimposed one upon another, so as to constitute a membrane of considerable thickness” (n. 116). And Heister observes, that this coat “is a dense and thick tunic, made up of a vast number of plane muscular fibres, surrounding the arteries like a circle or ring, and which tunic, by reason of its thickness, is also readily divisible into several layers” (n. 120). Boerhaave states that the muscular coat “is made up of highly elastic annular fibres, many rows thick, and divisible into a number of lamellæ ;” and that “the second is a thin and cellular coat, very dilatible when its cells are inflated ; and which, by pouring forth an oily, fatty and lubricating fluid upon the muscular fibres, admirably fits them to perform their incessant contractions and

expansions" (n. 126). Morgagni says: "I doubt . . . whether the fleshy fibres in the tunics of the arteries 'are spiral and longitudinal,' and serve the purpose of elevating and dilating the artery, as in the intestines; just as if there were no other circumstances to be taken into account in the arteries, and as if ample reason for their elevation and dilatation were not to be found in the intrusion and forcible propulsion of the blood" (n. 119).

183. Merely then from its description it is evident, that in this muscular coat lie all the strength and force of the artery. For its motive circles encompass the artery in a dense series. They are continued from the heart even to the minutest vessels. To these circles belongs the muscular force. They are condensed and strong in proportion to the magnitude of the volume they propel. For this reason the heart, which propels the largest volume, is one entire muscle, proportioned in its dimensions to the volume it has to urge; next in dimension after the heart follows the aorta, which is evidently possessed of a sphincter muscle and fleshy girths. After this there is in the artery a successive decrease in the number of forces, in proportion as the enclosed volume of blood successively decreases in magnitude and encreases in aptitude for fluency. Moreover, the artery compresses the finger when inserted into it, repels the entrance of air, carries forward an injected liquid, and after death, if an artery be tied so as to intercept its communication with the heart, it will, even below the ligature, convey forwards injected liquor, and urge onward as its own proper fluid, entrusted to its own management, the wave it encloses, and which regards every point in the artery, from the place where it was injected, as its own proper heart. The compressive force of the artery is the greater in proportion to its greater degree of expansion, for when expanded it has a tendency to return to its least diameter. Its fibre can receive inspiration from the brains; can also by twitching be irritated and fretted; can grow angry and infuriated with inflammatory applications; can be mollified by such as are tepid and soothing; and indeed can assume a diversity of states (n. 181): so that what Manget says upon the subject is not far from the truth; namely, "that the strength of the artery is derived entirely from the muscular coat, and that if this



coat be lacerated, cut, or dilated by any force, external or internal, an expansion of the artery, or an aneurism, is the result; for the intrinsic softness of all the other tunics causes them to yield at once to the pulsations of the blood" (n. 118). On which subject [of aneurism] we refer the reader to Lancisi.\* The other [subsidiary] tunics exist for the sake of the muscular tunic (n. 140). This tunic preserves a similarity to itself in the capillary vessels, where Leeuwenhoek "found its fibres stretching round the artery, so that this tunic, being exceedingly tough, was more adapted to the expansion or contraction than to the elongation of the artery" (n. 125). Through this small cylindrical canal some little drop or particle is frequently transmitted, which is not in contiguity with its antecedent, and which is thus independent of the motion of the heart. Nevertheless, all these become duly put in motion, inasmuch as the principal and proximate cause of the general pressure, as well as the concomitant cause of the circulation, has its residence in the muscular tunic. Assuredly, then, even the least resistance, either of the current parts of the blood, or of the vessels, would superinduce a general resistance of the whole and a state of quiescence. The sphere of activity therefore extending between the heart and arterial extremities, does not belong to the heart alone; for without the aid of the arteries, the fluid would froth *in limine*, and be reluctant to move on, while its impetus would continue to languish till none remained to urge forward the blood. All the force exercised by the heart may be accounted for in its injecting the wave, which arrives at the end of its course only in the extremities; and when it has arrived there, the heart may be considered as having discharged the whole of its functions.

184. Now what do all these things tend to shew, except, 1. That by the help of its tunic a vessel reacts as much as it is acted upon, and that it suffers itself to be expanded and compressed at a given ratio, with a view to which the texture of motive rings is capable of being folded and unfolded. 2. That every arterial point exercises a certain force of pressure, and that there is no part of the enclosed fluid to which there does not correspond some assigned force of the motive fibre. 3.

\* *De Motu Cordis et Aneurysmatibus*, ed. i., folio, Romæ, 1728.—(Tr.)

That the pressure of the tunic is continuous, and of the same kind with that which is exercised by the heart at distinct intervals. 4. That the artery receives into its open embrace, cherishes, and adopts as its own, the wave which is thus poured in; that it then with a *vis a tergo* urges it forward toward the arterial extremities. 5. That the sanguineous stream cannot be intercepted and stopped by any osseous or cartilaginous [deposit], by any aneurism, or polypous substance, provided it does not altogether block up the passage; for the blood has no more difficulty in passing through a temporary channel of this kind than in passing through the tube inserted by Vieussens (n. 178); or as in the case of an incision, through the aperture into the air: because when a force acts in a duplicate or increasing ratio, it does not cease at the instant of the next force ceasing to be superadded, but remains equable in the ratio which it had acquired, until it reaches the next point of progression, according to the law of motion belonging to fluids, and particularly where that motion is undulatory.

185. From these observations the reason is evident for which the arteries are soft, flexible, yielding, and not hard or uncompliant, otherwise they could not be acted upon by any undulating fluid, nor could themselves react upon the fluid. In order for anything to be, action and passion are both requisite, and there must be a concert between the two, in order that the effect may be perpetual and may respond to its one and only universal first principle.

186. Thus likewise the reason is evident for which the rings are not spiral but circular; for in consequence of their being circular, when the series is divaricated they only untwist, and do not stretch out longitudinally, neither is more of their texture opened than is proportioned to the difference between the previous diameter of the artery and the existing diameter of the wave; a difference to which the arterial swelling or dilatation is exactly equal: it would be otherwise if the muscular texture were longitudinal-spiral, instead of transverse and annular; for in this case the artery would not urge the enclosed volume in a forward direction toward the extremities, but in a backward direction toward the heart. Hence it follows, that as many as are the circles in series, so many are the forces in contiguity, and



from these forces thus multiplied, and subtended by one common tunic, there arises one continuous force accommodated to the wave which is transferred. Hence what exists in the arteries as continuous, exists in the heart as contiguous; for which reason the arteries have circular fibres, and the heart oblique and spiral fibres; for the latter propels the sanguineous volume from the narrower part of its ventricle or from its cone, into the broader part or towards its base, and thus *that* is effected in an antecedent direction which is immediately after effected in a consequent direction, or as soon as the volume is received by the artery, whether it be the pulmonary artery or the aorta.

187. *There is also required an interior membrane, whose office it shall be to collect these rings, and to determine them to the production of this general effect in the manner which we find obtaining in the arteries.* “The fourth and internal tunic,” says Verheyen, “is the thinnest, and is almost entirely membranous, or if you prefer the term, nervous. Its fibrillæ extending longitudinally, cut the annular fibres of the preceding tunic at right angles” (n. 116). And Boerhaave says: “The fifth and last coat, which lines the internal surface of the artery, is thin and membranous, and appears to consist of longitudinal fibres, which are contractile, like those of the fourth coat” (n. 126). Morgagni has the following words: “For my part, . . . I do not acknowledge that there are any sufficiently manifest longitudinal fibres in the internal coat of the arteries. . . . In fine, I observe in the arteries no fleshy fibres at all, except such as are annular” (n. 119).

188. Since therefore this innermost tunic, which is smooth, common to all the fibres, universal, thin, but strong and contractile, subtends and collects the series of encircling motive rings, what does this circumstance tend to shew, but, 1. That it collects into one its separate forces, or compacts and determines into one common pressure, the little individual compressory forces. There is nothing better known in mechanics, than that when several separate powers of one and the same nature, which otherwise would act one by one, are reduced to one common power, by means of some other which is continuous and extended below, above, or beyond the rest,—the power which

thus subtends, also adjusts\* and directs them. 2. That it restores tension, adapts the compaginated series to the wave as often as it passes by, restores to the fibres their natural situation and mode, and prescribes to them their laws of extension and compression. 3. That this it does more especially in the arteries, in which the common cause is carried on, at the same time that the particular cause of all things is carried on; and that it is both upon the equilibrium of pressure exercised by the arteries, and upon the circulation of the blood, that the whole natural economy depends; while nothing is permitted to be transacted in the system, to the execution of which the brains did not conspire, whose fibres therefore flow by continuity from this most universal membrane. See n. 137.

189. From a careful consideration of these circumstances, we are now at liberty to form a conception of the manner in which the wave once injected into the arterial cones, afterwards propels itself and is urged forward through the whole length of the arteries to its ultimate limits, with the greatest facility, yet with the greatest force; for there cannot be a more efficient, but at the same time a more easy, mode of exercising force, than the one presented to us in the case of undulation. The propulsion of the wave then we may conceive to take place in the following manner. If at the moment it is emitted from the heart, it assumes the inverse figure of the heart, but the direct figure of the arteries, it becomes parabolico-conoid, being broader at its upper part, and narrower and more acuminate at its lower, just as in the case of water thrown into a similar state of fluctuation. Hence the blood, when it distends the artery beyond its previous width, compels it also the more strongly to react in a direction toward the ramifications. This is the case not only with the larger volume, but also with the smallest, or even with a particle, percolating the capillary tubes, where being in the close embrace of the vessel, it is consequently urged forward by this means alone to the beginning of the veins. For Leeuwenhoek “observed that in a tadpole the particles of blood were flat and oval, and that sometimes, by reason of the tenuity of an artery, they were made to assume a

\* Coaptet.



tapering figure;" and [in human blood], "that in proportion as the larger [globules] were stretched out or elongated, the smaller assumed the same lengthened figure, till they became like threads;" and again, "that the globules, . . . in passing through the small capillary arteries and veins, changed to an oblong figure, . . . three times as long as broad" (n. 29). Hence it follows, that the force of the tunic, multiplied into the yieldance of its fluid, produces a conjoint effort, which is always on the increase from the trunks to the branches, and from the branches to the capillary vessels. But dismissing the consideration of these particulars, which obscure the series of universal and general principles, let us proceed to the investigation of the veins.

190. *The case, however, is different in regard to the veins. In these there is no circulation, but a bare impletion and depletion, or a pressure upon the blood they contain equally in every direction, upwards, downwards, and laterally, as exemplified in liquids filling conical vessels.* That the successive circulation or undulation of the sanguineous volume ceases at the termination of the arteries, and that another circulation commences at the beginning of the veins, which is rather to be denominated adimpletion or equation, is attested by a comparison of the arteries with the veins; by the cause of the circulation and of the pulse, which in the veins ceases; by the definition of undulation, which does not agree with the phenomena of venous circulation; by the essentials of the blood, which are changed immediately on its transition from the extremities of the arteries into the first beginnings of the veins.

191. This position is also confirmed by facts. For, 1. The veins are destitute of all pulsation, consequently of all transference of undulation from one place to another. 2. They are provided with valves, which the arteries are not. "In the cavity of the veins," says Verheyen, "at different intervals, there are certain very thin, light pellicles, called valves, which at one extremity, namely, toward the smaller twigs, are continuous with the interior venous coat, while at the other, [namely, toward the heart,] their edges are free. . . . They are frequently found near the divisions of the veins, or the junction of the branches; and sometimes are single, sometimes in pairs,

sometimes in triplets, &c." (n. 116). Bidloo "represents the veins as having, not only single valves, but sometimes as having two, three, and even five at a time, some of them conoid and pyriform, some semilunar, others semiorbital. Furthermore he states, that these valves lie at very different distances from each other along the veins" (n. 117). These circumstances clearly indicate, that the veins exercise no perpetual joint nusus tending from a smaller to a larger branch, but that they even exercise a joint nusus tending from a larger to a smaller branch; that is to say, a joint nusus tending upwards, downwards, and laterally; for Verheyen says, [speaking of the single and compound valves,] that "the latter are placed anteriorly and posteriorly with respect to the body, while the former [or the single] have a lateral position, or *vice versâ*" (n. 116).

3. The veins moreover actually carry back the blood. This is proved by the reticulated valve of Eustachius, which being placed before the entrance of the vena cava as it ascends from the liver, occupies its half and anterior portion, and then forms a bag, which is concave upward and convex downward. Respecting this valve see Eustachius, Lancisi, Winslow, and Heister (n. 120). Through the lunated portion and the reticular areas of this vein a very copious reflux of blood takes place, which when the auricle is compressed, cannot be sent into the right ventricle of the heart.

4. When the veins are tied, there is an equable intumescence between the ligature and the extremities, while there is an equable detumescence between the ligature and the heart. The case is different in the arteries.

5. In the blood enclosed in the veins there is a flux and reflux, as if its course were indeterminate, since the blood does not flow into them from the arteries at any stated intervals; as Malpighi has observed in the pulmonary [?] veins of the frog. His words are as follow: "When a ligature is put upon the [frog's] auricle and heart, and the motion and impulse prevented that might otherwise be communicated by the heart to the vessels, still the blood is sent by the veins towards the heart, so as by its force and quantity to distend the vessels; and this lasts for several hours: but at length, especially if the parts be exposed to the rays of the sun, the blood ceases to be actuated with the same continuous motion, and fluctuates, as



if impelled by fits, going backwards and forwards the same way ; which will occur even when the heart and auricle are torn off" (n. 123). In the arteries the case is altogether different ; for if any one of them be tied, it will be found that below the ligature they soon become empty, neither is the blood tardy in making its exit. 6. When a vein is opened, it projects the blood, according to the degree of pressure, in any direction we please ; as we may see by inserting a small tube into the aperture made by a lancet, and guiding the tube with the hand. A similar law obtains in the arteries, but when they are tied with a ligature, there will be found below the ligature, where the circulation is interrupted, a different sort of efflux prevailing. For while the arteries are pressing the blood in a forward direction, the blood is pressing upon the arteries in a lateral direction ; in the same manner as streams, which do not lose the property of lateral pressure because they may happen to be tending downward. Were the case otherwise, the artery would neither become expanded nor would it pulsate.

192. This proposition moreover is consonant to reason, particularly if we compare the veins with the arteries. For we may not unsafely conclude from the character of the tunics to the nature of the blood, and to the manner in which it acts (n. 135). Thus, 1. The muscular tunic of the veins is invested with a simple series of motive rings ; this tunic is the inmost, and is not subtended by any other that collects the single forces of the fibres and combines them into one common force, as we find to be the case in the arteries. "The fourth and inmost tunic [of the veins]," says Verheyen, "like the third tunic of the artery, consists of annular fibres, but thinner, and arranged in a very simple series" (n. 116). And according to Heister, "the veins are composed of a membranous, a vascular, and a muscular coat, but these are much thinner than in the arteries" (n. 120). Boerhaave observes of the veins, that "all their membranes are much thinner and more inert [than those of the arteries]" (n. 126). Thus each particular motive fibre in the veins singly and separately acts upon the blood enclosed within it, according to its own potency, force, nature, and inclination ; and when any one of the fibres exercises its force of pressure, the pressure is not determined, but is exercised upon

the sanguineous fluid indeterminately, which is thus compelled to react by pressure in every direction. 2. The blood flows into the vena cava, and the sanguineous stream is received from innumerable venous origins. The case is otherwise with the arteries, into all of which there is only one influx from one fountain, namely, the aorta; while on the other hand, the vena cava is like a lengthened conduit pipe, which admits of as many little waves as there are inosculating branches; hence there cannot possibly result one particular, but only a common or general pulse, or impletion. The same law obtains in the branches, which receive the sanguineous tide from their twigs in like manner as the common recipient trunk receives it from the branches. It follows, therefore, that in the case of a multiplicity of currents discharging themselves into one common trunk, and one common current discharging itself into a multiplicity of vessels, the law of progression is not similar. 3. This flow of blood in the veins does not take place at regular stated intervals, but at several different moments and almost continuously. It comes, for instance, at different moments, from various members of the body situated at a distance from each other in the system, as from the wrist, the palm of the hand, the thumb, the forefinger; or from the ankle, the heel, the sole of the foot, the toes; or from the legs, the thigh, and abdominal viscera: consequently, the wave nearest the trunk has precedence of the others more remote. It comes at different moments from the muscles; for the muscles lose their blood, grow pale and constricted, according to the motions, wills, and natural instincts of the mind, the blood of the muscles being at that time wholly expressed into the little veins; a circumstance which takes place whenever the will acts, whether the heart be in a state of systole or diastole. At different moments it comes from the glands, vesicles, and pores, which are all muscularly acted upon, and excited to act according to their several appetencies which are continual; and when excited, they present the food to the hungry veins, as the stomach, mesentery, and thoracic duct present their chyle to the subclavian vein. It comes at different moments from the sinuses of the brain into the jugular veins, and at different moments again from the azygos into the heart; for being annexed to the



bronchia and trachea by membranous and vascular prolongations, it does not infuse into the cava the sanguineous fluid it contains, except at the moments of pulmonary expiration. The intercostal and other veins in like manner discharge into the azygos their united streams, derived from the whole respiratory field of the lungs. This, I think, will be most satisfactorily shewn in Part II., treating of the Blood-vessels and Motion of the Brain. It is again at different moments that the blood is derived from the liver, pancreas, diaphragm, kidney, genital members, womb, &c. So that the veins are receptacles of a sanguineous afflux which is continuous and not discriminated by the beats of the heart. The case however is different in regard to the arteries, for here the blood is infused from the aorta at the stated moments of the cardiacal beats, and being conveyed progressively from one place to another, occasions an elevation, and consequently a pulse coinciding with the beats. Thus the blood has so composed a system of little arteries united by anastomosis with those which are more distant, that at the same beat the sanguineous elevation can be present at every point, whatever be the part from which the blood has flowed, and whatever the part to which it is flowing. 4. The blood is not transferred from the arteries to the veins, nor does it enter into the veins, the same either in quantity or nature as it was in the arteries. It does not flow into them the same in *quantity*, because the serosity of the blood is separated by the arteries; as is proved by the excretion of urine, sweat, insensible perspiration; by the occasional accessions to the blood arising from periodical meals; by the tendency of the body to become fat; by the continual renascence of the frame: hence it is not the whole sanguineous volume that circulates from the arteries through the veins to the heart, but merely a certain selected portion, or that which is reabsorbed from the vesicles, ducts, and pores, through the orifices and lips of the little veins. Again, the blood which flows into the veins is not the same in *nature* with that which flows into the arteries, for their excretions and outcast materials are not swallowed again by the veins, which are choice in the selection of their food, and cull out only such portions as are adapted to reënter into the composition of the blood. The volume of arterial blood therefore is for

the most part not continued through the veins, inasmuch as the blood upon its arrival at the veins is no longer the same either in quantity or nature. Neither is the blood infused into the veins, but is rather taken up or received by them, as also by the little cavities and spaces where the secretions are performed (n. 205). Hence there is no injection of volume into the veins, consequently no distinct origin of any wave, nor any transmission of the blood originating in the exercise of a compulsory force, this being an essential characteristic of the arterial circulation. 5. The wave itself, such as it is described in n. 189, cannot be sent through a smaller into a larger tube, for if so, it would immediately disappear, and assume the character of a volume pressing upwards, downwards, and laterally; for it cannot be rendered wider posteriorly, and narrower and more pointed anteriorly, since the venous tube itself enlarges as it proceeds. From these remarks we see how it is that the blood can retrograde through the smallest arteries; the little canals being cylindrical, not conical. "In a frog, . . . Leeuwenhoek saw that the blood running in the great artery, and derived into a twig or little artery, was sometimes suddenly stopped in its progress, and even retrograded till it was refunded into the great artery, by which the beforementioned twig was given off. . . . After a short time . . . the blood again resumed its ordinary direction and rapidity" (n. 125). And Heister observes that, "in the extremities of the body, . . . the twigs become cylindrical canals" (n. 120).

193. Moreover, the use and function of the veins demand the substitution within them of a mere process of impletion and depletion for that of a circulation; for they are required to receive the proffered blood at different moments; to imbibe the fluid which is to be mixed with it, from innumerable receptacles and other sources (n. 49, 50, 53); to perform the commixtion of the whole; to recompose the sanguineous particles in their order; and to be the first to commence the process of natural chemistry: all which things could not be done were the blood transferred by any violent motion through a circle as in the arteries. To accomplish these purposes, a more quiet and less active state is necessary, a cooler temperature, and an equal pressure in every direction.



194. The state of the arteries themselves likewise demands this provision, in order that the arterial blood, after pursuing its laborious route, may have asylums to which to resort, whether the quantity of blood be a small portion, the greatest part, or the whole, as depending upon those variations of the equilibrium which arise from the changes of body and mind, occurring in states of animosity, anger, fear, terror, &c. (n. 181); as also at death, after which commonly no blood remains in the arteries, but the whole withdraws itself into the veins. Thus the veins may be called the receptacles or passive vessels of the arteries, the subjects and adjuncts of such as are active.

195. The motion of the heart likewise demands this provision. For were the blood poured into the heart in the same manner in which it issues from the arteries, the motion of the heart would be subject to perpetual changes, and indeed would actually be changing every moment, according to the different affections of the arteries. This change in its motion, however, does not appear to be produced, if we may judge from its equable and steady vibration, however largely the veins may turgesce, or however closely they may collapse, provided the fibre be not incited or stimulated to too strong a pressure. This we see illustrated by the practice of venesection; in which we find, that from those who are in a state of fear frequently not a single drop escapes, although there is a large quantity of blood in the veins. For the fibres of the heart are incited to a *vis agendi* by a cause which is either internal or external: internal, when they are acted upon by the brain; external, when they are acted upon by the blood, and by rough, hot, inspissated serum. The motion of the heart would instantly cease, did the same urgent, undulating, and circulating force press upon the right auricle as upon the aorta; as we shall shew in Chap. VII. of this Part.

196. Thus we are enabled to assign the reason for which the veins are more inert, of a cooler temperament, and much more expansile than the arteries; their blood not so red and bright, and when drawn, not so rapidly tending to coagulate; why they are of larger diameter; why they accompany the arteries laterally, and frequently climb up upon them, as in the brains, dura mater, and other places. The case would be otherwise if

there were undulations in the veins as there are in the arteries, and the wave of the one hurried on with a pulse and stream contrary to that of the other; for then opposition, discord, and a destruction of the two motions would arise. We may see also the reason for which the vein can be opened without danger, its membrane grow together again, and the wound close up, differently from what takes place in regard to the artery. We may finally see the reason for which the dispute on the circulation of the blood, as discovered by Harvey, so long continued; since the arguments against it were derived, not from the phenomena presented by the arteries, but from those presented by the veins.

197. From these remarks it follows, that such a circulation as prevails in the arteries cannot take place in the veins, but that in the extremities of the arteries there is an end of the circulation,—if by the circulation we understand the successive transference of the undulation. For after the blood has passed these extremities, it is received into the veins, not as bringing with it a pulse, but as a simple equation or impletion; although this may perhaps with propriety be called a common or general circulation. The case, in fine, is the same with that in which water is received into a conical vessel through different apertures. From these remarks it follows, that while there exists a larger volume of blood in the venous twigs below the valves than above them, the volume below depresses and crosses over them, and pushes onward, in order that the whole may be in the same state of equation as its part. Hence there arises an augmentation of forces and a conjoint nisus into the larger vessels, because the blood exercises its conatus in the veins as water does in conical vessels, that is to say, as much upward as downward; its force increasing in the simple ratio of the areas. Just as is the case with every other liquid enclosed in cavities, and similarly compressed on every side, according to the experiments of Pascal and others.

198. We have thus satisfactorily proved the following proposition,—*That in the case of the veins, the influx of the sanguineous stream is from innumerable origins of these vessels, and their reception of the stream does not take place at any regular and given moment, as in the case of the arteries, but at several different mo-*



ments. *This sanguineous and venous stream, moreover, discharges itself into the chambers on the right side of the heart by a solitary venous sinus ; thus presenting an arrangement altogether different from the one we find prevailing in the arteries.* The reason, as above pointed out, is, that all the veins whatever, are only receptacles of a continuous afflux, and not of an afflux discriminated by the beats of the heart. See n. 192.

199. *The general pressure and circulation of the sanguineous volume being given, and compared with the condition of the vessels and with the nature of the arterial and venous blood, it follows, that the arcana of the science of angiology may be referred to the following general heads.* I. *That proper liquids and elements be conveyed to the blood.* Food, for instance, converted into chyle, must be conveyed through the gullet, stomach, intestines ; from these to the lacteal vessels, and thence to the blood (n. 49). Atmospheric aliment must be conveyed to the lungs, and by means of the lungs to the blood (n. 50, 51). Most subtile ethereal aliment must be conveyed to the bibulous layers of the skin, and through these to the blood (n. 53—58). Moreover, from every pore, vesicle, and gland, aliment must be provided, which has been repeatedly secreted, and which is destined for the little veins to swallow and to ruminate. The first rule therefore is, that suitable food be procured, absorbed, and conveyed through the body in the form of a liquid. II. *That in the blood they receive a due commixtion.* For instance, that the purest aliments be conveyed into the smallest vessels ; that into the vessels which are somewhat larger, be conveyed the aliments which are next in degree of purity ; that into the vessels which are next larger, and into those which are largest, be conveyed the aliments which are in a grosser state, as exemplified in the chyle which is conveyed, though not always pure, into the subclavian vein. For in the same order in which the blood is depurated and resolved, in the same it is commixed and remade (n. 151, 154). All this must be done, in order that in the right side of the heart there may be a perfect commixtion and fusion of all the aliments received, it being there that they are as it were in their state of chaos, or only as an undigested volume ; for there the inspissated substances are associated with the thin, the sluggish with the fluid, the inert with the active, the non-elastic

with the elastic, the heavy with the light, or the serum with salts of every class, with the spirituous fluid, with the simple, and with the compound blood. III. *That they be duly insinuated into and presented to the blood*: that is to say, through the serum to the blood. To enter into the order in which these are severally fitted into the individual particles of the blood, to the intent that they may all exist in a state of combined fitness, is to enter into the question as to the particulars composing the common or general whole; a question which relates therefore to the manner how they do so, and which will, to a certain extent, be considered in an ensuing chapter. We may however thus far remark, in anticipation of what we have there to state, that so skilfully has nature devised her manner of progression, that nothing is impervious to her in her course, nothing presents to her the slightest obstacle, since she proceeds from first principles to causes, and from causes to effects, or successively through degrees. It is by a mode of her own that the ethereal elements are engrafted into the pure blood, and the aëreo-saline and the terreo-saline into the red blood; to the end that all the substances she has adopted as her own may so preserve their form, maintain their connection one with the other, and perform their several functions, that they may never cease to serve the purposes of the soul (n. 46). IV. *That they be duly separated*; or discriminated: the heterogeneous, for example, from the mixed homogeneous, and the mixed homogeneous from the pure. For assuming that there is in the heart a promiscuous volume, a chaos of thick-coming fluids, then in proportion as the mass moves on into a lighter region, the inspissated are removed and separated from the thinner, the sluggish from the fluid, the inert from the active, the non-elastic from the elastic, the heavy from the light, and at length all the serum from the pure blood, as we see to be the case in the macrocosm or in the atmosphere, with which we may legitimately compare the case. How this is brought about, Baglivi informs us when he says, that [in a frog that he opened for the purpose] “at first the blood ran through the vessels with the greatest rapidity, as it were in straight lines. . . . These straight lines moved more rapidly in the middle (centre or axis) of the vessel, than about its sides; and the nearer they were to the sides, the less was their velocity. When



the frog was almost dead, the above rectilinear currents were more slow, and instead of having a progressive motion, began to be deflected to the parietes of the vessel in various parts" (n. 124). Reason here supports experience. For when a feculent and mixed volume, after having been purified in the lungs and liberated from flatulent substances, is hurried through the arteries at a rapid rate; and when at every single point the wave is pressed upon by the muscular tunic, it follows that the more sluggish, inspissated, inert,\* inelastic, rude, angular substances, in a word, such as are the least adapted for fluency, will occupy the circumferential parts, while all the rest will occupy the axis, whose interior the intermixed spirituous fluid will occupy, and next in order, the impurer, darker, heavier, or spurious blood. All these things are effects resulting from the common pressure, and from the circulation of the wave in the arteries. V. *That they be held in a state of sequestration.* For in the minuter vessels, the blood, during its flight, directs its course along the axillary line, and presses the circumfluous serum so closely to the peripheries, that the latter leaves the stream and is held in a state of separation. For from the extremities of the arteries numerous mucous villi, little spirals and open mouths are suspended, to convey away the fluid; there are also little cells and follicles, and cavities and tubes of every dimension to receive it; each of which is filled with its own dewy and vaporous element, its own liquor and collected stream; so that in no viscus is there any membrane, fold, or tissue, into which the blood finds its way, that does not provide a reception for the serum which has escaped from the arteries. "These arterial extremities," says Boerhaave, "terminate either in the beginnings of the little veins by a continuous canal, without any intermediate parenchyma [or cavernous structure]; or else in crypts, or follicles, or in the large or small cavities in various parts of the body; or in excretory vessels; or in particular si-

\* We must suppose that these inert particles are also unadapted to receive the spirituous fluid exhaled from the interior tunic, or else the very fact of their being in contact with the tunic would only tend to increase their velocity; as is stated to be the case in the capillary vessels, where a single particle is embraced on all sides by the tunic, and yet is said on that account to proceed with the greater rapidity.—(Tr.)

nuses, as those of the penis, clitoris, and spleen ; or directly in secretory vessels ; or perhaps, lastly, in a glandular pulp” (n. 126). And Heister observes that, “the twigs [of the arteries] . . . terminate sometimes in reticular plexuses, sometimes in little brushes, spirals, glomes, &c ; and at length in serous vessels, veins, lymphatics, or excretory ducts” (n. 120). VI. *That in this state of sequestration they be eliminated.* They are to be duly eliminated : that such is actually the case, we are led to believe from the excretion of urine, sweat, saliva, mucus, effluvia, different kinds of fluid elements, as well as from the other excretions, which are no longer of use. For this reason there are provided such a large number of glands, with their filters and little excretory ducts, that there is scarcely anything in the compages of the human body that is not in reality transpirable. Moreover, there are some substances which are sent away from the blood, not as outcast and obsolete, but in order that in their circle they may fulfil an appointed use ; as the gastric and pancreatic juices, the bile, and the lymph ; other substances there are which are separated, with a view not to present, but to future use ; such as semen, aliment for the embryo, milk, &c. Or they are to be duly *reabsorbed*. Liquor which has once been separated from the arteries, depurated from what is useless, and again divided in the arteries, is often recalled into the blood by the veins, whose numerous lips lie open, and whose pendulous little dugs as it were are fed and suckled by such things as agree with the blood transmitted from the arteries through short passages belonging to the veins. If there be any lack of nutriment, the hungry veins will feed upon the fatty substances contained in the follicles, even to the superinducement of exinanition and emaciation. The pure saliva of the lymphatic vessels, the gastric juices, bile, with numerous other essences and primary fluids, they eagerly snatch. “Their extremities,” says Boerhaave, speaking of the veins, “are various, as we observed to be the case in the arteries ; some of their radicles commence from the little bibulous mouths of the cuticle ; some, from the absorbent ducts placed all over the body, in the internal, hollow membranes that form crypts, follicles, or large or small cavities ; others arise immediately from the extremities of arteries, or else from certain singular analogous channels or



sinuses, as in the penis, clitoris, and spleen ; or lastly, perhaps from a glandular pulp" (n. 126). VII. *That the very blood globule itself undergoes resolution and reunion.* On which subject, see n. 149, 150, 158, *seqq.* In order to collect the testimonies in favor of this position, it will be desirable briefly to recapitulate the arguments which have been adduced. They are as follow. From the evidence furnished by experimental facts, we find that the blood flows through the capillary arteries, either undivided, or separated into spherules : that these spherules suffer themselves to be moulded into oval figures, and that the smaller spherules composing these, suffer themselves, with the greatest ductility, to be elongated into filaments : that the blood is softer and more flexible in healthy persons, harder and more renitent in the sick : that it divests itself of its redness, and assumes different colors, varying from black to pale, retaining none of its own color in any of the smallest stamina, or in any secretion : that previously to this the red blood nowhere enters into the cortex of the brain, but deposits without the volatile salts which have an ammoniacal odor ; so that the fibrils of the brain distend with an abundance only of spirituous fluid : that the blood is of one character in the arteries, of another in the veins : that arterial blood is soon coagulable, is redder and warmer than venous : that venous blood is thinner, more diluted and colder than arterial : that this is the case also when the blood is abstracted from its vessels. Hence it follows, that the blood suffers itself to be divided, if there be a divisor ; and that such a divisor is found in vessels and fibrils of a superior order has already been shewn. For there are as many degrees of arteries as there are of the composition of the blood, and for this reason, that each requires its own correspondent. If the blood had not possessed this susceptibility of being divided, it would, after a certain number of circuits, become loaded with heterogeneous substances, relax its speed, and form into fibres ; in the larger vessels it would be held in detention, and would only clog the entrance into the intimate recesses of every texture. Even, however, were this not the case, the offices exercised by the soul and spirituous fluid would become disturbed, and the blood would no longer feel its due appetency for daily renewal by alimentary substances. Since, therefore, the blood is thus re-

solved and reunited, it is in a state of perpetually renewed formation and existence; it is always fresh, and ready for any and every use; it never grows old or obsolete, or if it does, from that moment it is clad in black garments and borne away to the tombs of the liver. Hence it is in a state of perpetual birth, death, and rebirth, and is every moment forming some incipient stamen both of our life and of its own. That the blood is thus passing through the same mode which it commences in the chick and embryo from the first state of the egg, will be demonstrated in the subsequent chapter; and in the course of our several Parts it will be seen, that otherwise the animal economy could not last a single night, much less a whole year.

200. But these laws of the blood may be still reduced in number, and further generalized. Thus, 1. The individual particles of the red blood are to be united together, and afterwards resolved. This is the cause, or the *materia propter quam*. 2. The component elements are to be commixed and separated. This is the cause, or the *materia ex qua et per quam*. *All of which processes must be in continual operation.* But how they are all carried on in the several viscera, as in the stomach, intestines, spleen, liver, and pancreas; in the lungs, trachea, and palate; in the womb, mammæ, and genital members; in the muscles, brains, medullæ; in the membranes and meninges; in the cartilages and bones,—this will be explained in specific Parts on the above subjects; for the science of these things is the last that can be brought to maturity (n. 9, 10, 16), and cannot therefore be fully explained till we have advanced toward the conclusion of our work.

201. *The apportation, commixtion, and insinuation of the liquids and elements, in a word, the entire composition of the blood, is effected in the veins.* I. That the veins *suck in* the liquids and elements *conveyed to them*, such as the chyle, &c., there is no doubt; their mouths and lips lying open wherever there is any liquid to be absorbed. That the veins *commix* the elements and liquids according to degrees, and that all these are ultimately poured together and rolled about in the heart, as in a cauldron or whirlpool, see n. 199. II. That they are there *insinuated* into the blood, see n. 199. III. Hence the state of the



veins is more quiescent, they are of a cooler temperature, and more adapted to the task of compounding the various elements; nor is there within them any violent propulsion or circulation of the blood (n. 191—197).

202. *But the separation, sequestration, and elimination, in the arteries* (n. 199, IV., V., VI.) Thus the functions of the animal kingdom are constantly passing, according to stated laws, through their several cycles, in unison with that of the blood above described; and thus the general propositions of which we have hitherto been treating are accordant with each other.

203. *The more complete therefore is the state of purification from serum in which the blood is conveyed immediately from the arteries to the veins, the more nearly does the circulation approximate to its natural and most perfect state.* That the arteries are continued into the veins, is a fact which admits of no doubt. Thus Leeuwenhoek states, in speaking of the tadpole, that “it became evident to him, that the blood-vessels observable in this creature, and which we are wont to distinguish into arteries and veins, are one and the same class of vessels” (n. 125). Nor is there any doubt that the serosity which accompanies the arterial blood, is, in the course of its passage, secreted in large quantities and exterminated from the blood, before the latter is infused into the veins (n. 199, IV., V., VI.) But the question at present is, whether the blood be so depurated from the serum, as that the portion which is continued into the veins is perfectly pure, and entirely separated from its former associate. That the contrary is the case, I am induced to think, for this reason, that it is not always the smallest artery, or that which transmits only single particles, which anastomoses with a little vein, but even that which is much larger, wider open, and capable of conveying serum mixed with the blood. Still, however, I observe, that in proportion as this is the case, the circulation degenerates from its most perfect state, as it does, for instance, in every morbid constitution of the body; whence arise obstruction, vitiated chylication, inflammation, aneurism, ecchymosis; all which are indicated by variations of pulse, of respiration, of transpiration, and by innumerable diagnostic phenomena and morbid accessions, and which are so many proofs of a very imperfect circulation; that is to say, of a circulation taking

place only in the larger vessels, in consequence of the minuter ones being obstructed. And since at almost every moment it happens, that in consequence of the body or mind laboring under some ailment, the province of the minuter vessels is undergoing some change (n. 234, IV.); or that the arterial blood, in consequence of some undue relaxation in the vessels, rushes on a sudden into the veins; or is stopped in its progress because of the communication with the veins being closed, and is compelled to pass and repass through more open or wider vessels; since, I say, this is happening almost every moment, I am inclined to think that the blood which is continued into the veins is not perfectly depurated from serum.

204. If, however, we attentively look into the causes and effects of things, we shall see, that in the degree in which the blood is not depurated from the serum, or does not flow directly into the veins through the smallest vessels pertaining to its circuit, in the same degree also the circulation labors under a vitiated state, consequently the natural economy suffers detriment, and we are by an imperceptible progress led into diseases or into premature old age. Indeed, this is only a consequent of the preceding articles of this chapter, and the antecedent of those which follow; hence it necessarily flows from their demonstration. For, 1. The blood must be separated from mixed heterogeneous and homogeneous substances, in order that it may travel in a state of purity through its own proper region, where the blood is in a state most highly accommodated to the vessel, and the vessel to its blood; for these two would not act as one cause, if any angular, unequal, or rough substances accompanied the blood; such as are the saline particles of every class in their free state, aqueous substances, oils, and spirits, which in the most minute pores are incapable of yielding and adapting themselves; such, in a word, as is the serum. 2. Thus would the blood, in the minute fibres of muscles, hesitate in its course, doubtful which path to pursue, and unsubservient to the motions of the will. It would lodge also in the various glands or vesicles, into which it would no longer distil the liquids and dews, the commixtion of which gives birth to the animal juices intended for the various necessities and uses of the body. For when nature is in that atmosphere of extreme lightness, she is



desirous to make it the palæstrum of her physical and chemical exercises, consequently the blood is left to the jurisdiction of the vessel, and the vessel to the jurisdiction of its blood. 3. And unless the sanguineous volume were reduced to its units, that is, unless it were depurated from the serum, it could not undergo any process of division or section into its primitive spherules, consequently it could not enter into its universal gyre, or continue and complete it. 4. Nor would there be left to the veins the choice of such things as are necessarily and contingently required by the blood for the purpose of its renovation, and by the animal kingdom for its preservation; on which subject the reader is referred to the subsequent article. For the veins being disinclined to receive these aliments, wider channels would be employed, which would receive and transmit not only congruous, but incongruous substances. These arguments are however theoretical, but the mere science of anatomy can supply us scarcely with any other. There are however practical proofs of the foregoing remarks, derived from the history and science of diseases; from therapeutics, which prescribe the general rules for the art of healing; hygiene, which prescribes those for the preservation of health. For all signs of change in the constitution, all its phenomena and symptoms, are so many effects, which augment the number of sensible facts in evidence of the truth of our remarks. To this may be added what has been said in n. 162. Moreover, the experience of Leeuwenhoek confirms these views of the subject. "In the tails or fins of larger fishes he clearly saw a great number of blood-vessels, admitting only single particles of blood. . . . More than once he saw an artery of this calibre blocked up. . . . In one species of eel, between the several ossicles that form the extremity of the caudal fin, he saw the blood circulating in vessels through which two or more of its particles could travel abreast, and many of the arteries also were there inflected, and constituted veins" (n. 125). The vessel inflected itself in this manner, in order that it might have the opportunity of dismissing such particles as were not sanguineous, and that the pure blood alone might make its transit into the vein, according to the statement in our proposition.

205. *All other particles designed to form an admixture with*

*the pure blood thus propagated from the arteries into the veins, are imported by innumerable recipient vessels, ducts, and pores, of divers orders, and are seized by the little veins.* That it is the office of the veins to arrest and swallow such things as come into contact with them in the various vesicles, cells, and pores, is a subject on which I think no one entertains a doubt (n. 199). But we would now enquire whether such things only are imported to, and allocated at, the little mouths and lips of the minute veins, as are seized and swallowed; whether, consequently, there be not a cause operating from a different quarter in producing an apposition of aliments, antecedently to any choice exercised by the veins; whether, therefore, the veins, properly speaking, exercise no elective powers conformably to the structure of their little orifices and tubes, but only indiscriminately absorb whatever is brought to them. That such is the fact, we may infer, 1. From the food which is conveyed to the stomach, and the chyle which is conveyed to the subclavian vein. 2. From the intermediate mesenteric glands, which transfer and forward the aliments, and from the concatenated structure of the thoracic duct. 3. From the sacral and other glands, which urge the pure lymph of the lymphatic vessels toward the same duct. 4. From the aërial aliments, which are admitted with the air into the pulmonary cells; as also from the ethereal aliments, which enter into the skin surrounding the body, and present themselves to be absorbed by the veins. 5. From the fact that the brain, by means of its animation, presents to the old blood a new spirit, initiated into it in the venous sinuses; and that these present it to the jugular veins, and these again to the subclavian; all of which seize upon what is thus forwarded to them for their imbibition. 6. From the fact, that in the spleen and other similar cellular viscera, all the blood which is extravasated or expelled from the little arteries through the cells, is presented to the veins and is all imbibed, with the exception of the pure lymph, which is most copiously eliminated and derived into the lymphatic vessels, and not into the veins from the little cells just mentioned. 7. From the construction of the venous lips and mouths, which immerse themselves into the liquids conveyed to them, and indiscriminately suck them in. The mode and mechanism of which process will be seen in



n. 222. From these proofs, among which are presented cases where the operations are carried on upon a large scale, and which are obvious to the senses, we may conclude with regard to those in which the operations are not obvious, and which belong to the sphere of the smaller vessels; that is to say, we may infer that in the veins there is no secret power of attraction: that the whole arterial stream is not indiscriminately offered to the little veins, but only such edible portions destined and prepared for this purpose, as are suited to the blood and the kingdom; and that there is a cause altogether of a different nature which disposes the minutest follicles, pores, and folds, to convey those aliments to the veins, to form a commixtion of others, to prepare essences the most widely different, and to reject whatever is useless.

206. With what skill nature has so constructed her channels of communication, that nothing is imported to the veins except what is purified and in agreement with their nature, is sufficiently clear from this circumstance, that the blood in its first passage through the aorta, and before it arrives at the region of the minuter vessels, liberates itself from all spurious vehicles. It divests itself, for instance, of all impurities by means of the emulgent, which lead into the kidneys, where it deposits the urine and the useless and superfluous serum: it divests itself of all spurious substances by means of the hepatic arteries, which lead to the gall-bladder, where the hard, old, and obsolete sanguineous particles are deposited. And lest any blood accompanied by these particles should escape through the superior and intercostal arteries, which are very numerous, these vessels are extended, not at oblique angles, but at right angles from the trunk, &c.; and after having pursued its course till it has arrived at the smallest vessels, where the villous growth of the secretory vessels is suspended from under every offset, the blood then eliminates the other substances in their series, and such as are eliminated are afterwards dispensed one by one to their uses and ends, by means of that stupendous order of operations for which the economy of nature is distinguished. Were the case otherwise, we should have no means of ascertaining in what manner some arterial secretions are rejected, others intermixed to form juices of most different natures, and others brought

back again to the arteries ; or in what manner animal nature performs her various functions.

207. *Thus it is that the arteries hold in aversion and reject those things which are not suitable to the blood, while the veins seek out and procure to themselves such as the blood necessarily and contingently requires for its renovation, and the animal kingdom for its preservation.* To the arteries we attribute aversion, and to the veins appetency, in the same manner as we attribute nausea and hunger to the stomach, and thirst to the gullet, when nevertheless these affections are affections of the blood, in a state of common or general need, occasioning a similar state of need in the fibres and their fluid, hence also in the whole system ; whence there is excited a common or general affection of the brain, and which, as the brain is concealed from our notice, we are in the habit of calling natural instinct. The arteries are the instruments of rejecting those things from which the entire system is averse, and the veins are the instruments of procuring those things of which it is desirous. Thus, in proportion to the greater degree of aversion in the system, the greater also is the degree of general pressure and circulation assumed by the arteries, and the more openly do they expand their secretory tubes in the same moment in which the veins straiten, compress and shut their reabsorbitory tubes ; while on the other hand, in proportion as the system is in a state of appetency, the more openly do the veins expand their imbibitory lips and mouths, and fold them back or evert them,\* in order to become the more effectually drenched in the thick-coming stream. Hence their tunics grow dry, the palate is parched, all the extremities are in a state of hunger and thirst, and if no aliment be conveyed to them from any other quarter, or if this state of desire be not allayed, they feed on the fatty substances with which the membranes, mesentery, omenta, muscles, and glands, &c., are charged.

208. Nay, further, the arteries have an aversion and the veins an appetency for the ingredients which enter into the blood, not only with regard to their quantity, but also with regard to their quality. When there is a deficiency in the quantity of solid

\* Expandunt, replicant, resupinant, &c.



clements, of whatever genus and species, the veins hunger after them. When there is a deficiency of fluids, they thirst for them. When there is a deficiency of animal spirits, the conscious brain looks round upon the whole mundane system, in quest of a proper supply. Hence arises the longing felt by pregnant females for incongruous aliments, and which the young embryo sucks in for its own support. Aversion and appetite in relation to qualities are, however, common and familiar to brutes, which, under the tuition of nature, know what it is they ought to desire, what sort of food to eat, and what to reject. On the other hand, in the human species, aversion and appetite are almost entirely in relation to quantity; appetite being manifested by states of hunger and thirst, and aversion by states of fastidiousness and nausea. There is seldom aversion or appetite in regard to quality, except for the sake merely of the taste, or the idea of utility suggested to the mind; or except in cases of sickness, in which the idea of quantity may excite a certain obscure and indefinite sense of abundance or deficiency in quality. Thus we frequently nauseate what we before desired, and desire what we before nauseated, as though unconscious of the exciting cause. This cause, however, is to be found in the cerebellum, which is conscious of the state of the animal economy, and by dispensing these sensations, &c., through the medium of the glands, vesicles, and pores, through their muscles and fibres, arteries and veins, thus provides for the requirements of the system, the safety and preservation of which, both as to its whole and its parts, depend upon its own wise provisions.

209. These aversions of the arteries and appetencies of the veins arise, not only from a necessary, but also from a contingent cause; from such, for instance, as awakens those aversions or cupidities which for the most part have only a contingent existence, and arise from objects that are seen, heard, tasted, smelt, touched, imagined; whence the appetite for eating, drinking, sexual intercourse, and the occasional cause of anger, revenge, hope, love, fear, fighting, running away; at which moments the minutest organs of natural chemistry, its pipes, bladders and little ovens are all set to work, preparing and accumulating stimuli to forward supplies of blood, to throw

it out, to forward it to the veins, and generally to affect and modify it in a manner conformable to the contingent appetency.

210. *To prevent therefore any undue aversions of the arteries, or appetencies of the veins, as well as other contingencies, from proving detrimental to the animal economy.* We must again remind the reader, that aversions are attributed to the arteries, and appetencies to the veins, as to their proximate causes; when nevertheless these aversions and appetencies are those of the brains, which derive them from a previous change experienced by the system, and which afterwards act from them as from their own first principles. It is moreover to be observed that these appetencies are themselves the veriest efficient causes of many natural dispositions. So long as we live as animal beings, a perpetual round of cupidities is exciting the animal mind; nor indeed is there anything which more frequently affects it, one perpetually following upon the steps of another. Those which are short and just beginning, escape our attention; but as their duration lengthens, they extend their influence, and come within the sphere of the senses; thus they become conspicuous, and are called appetencies, passions, affections, cupidities. Unless by these the animal mind were constantly resuscitated and warmed, unless the fibre inhaled its spirit, the capillaries of the arteries and veins would lie idle and their functions discontinue; for these cupidities are media, which are employed as excitants of life, such being the will of the Deity. Unduly repressed or indulged, they become detrimental to life, and assume the nature of vices, which are the more inexpiable the more they invade the higher region of the mind, disturb and invert the operations of reason, engage it to find specious excuses, form second natures, and then cleave to us, and thus lay desolate the economy of the system, depriving it of the exercise of all public rule and authority. Lest, however, any undue repugnance of the arteries, appetency of the veins, or other contingent disorder, should prove detrimental to the animal economy,

211. *Nature has adopted a precaution in the establishment of a perpetual communication of the vessels one with the other.* This communication is thus described by Verheyen: "Not only," says



he, “are blood-vessels of different kinds connected with each other, but also blood-vessels of the same kind ; frequently, that is to say, veins with veins, and arteries with arteries ; so much so, indeed, that there are scarcely any considerable twigs running from the same trunk to the same region, but after their division again unite, at any rate by minute anastomoses. Most anatomists have hitherto considered such anastomoses to be confined to the regions of the head and uterus ; . . . but they are beautifully seen externally in the skin of a foetus of six or seven months” (n. 116).

212. *In the multiplication in every part of the system of causes appointed to effect one and the same purpose.* Respecting this multiplication, Malpighi says : “In the silk-worm . . . there . . . [are] certain remarkable ramifications of vessels,\* which run to all parts of the body. . . . These vessels . . . mostly form reticular plexuses, such as may be observed in the leaves of trees ; and this is more particularly the case between the muscles and the skin, where the luxuriance of these vessels is so great, and their interweavings are so wonderful, that it is impossible to have a more beautiful spectacle than they present” (n. 123). And Boerhaave says : “There is not a perceptible part, however small, in the compass of the body, but has its little artery ; as we are taught by the bleeding that follows small wounds, by the phenomena displayed by the microscope, and by the process of injection ; and this remark applies even to the very middle of the bones, where we find both membranes, vessels, and humors” (n. 126). I call the blood within its own vessels the efficient cause ; for the fluids represent nature and her forces, nay, also, the mundane system and its substances (n. 66). There is a multiplication of vessels therefore in every one of her degrees, as they proceed from their maximum to their minimum, or to their minima. Thus they decrease in magnitude, but increase in multitude ; for which reason, quantity, which involves as well magnitude as multitude, continues to be predicable of each extreme. Thus magnitude may here be called inferior quantity, which is the continuous quantity of the ancients ; and multitude, the superior quantity of the same degree, which is the discriminated quantity of the ancients.

\* See the note to n. 123, p. 90.—(*Tr.*)

213. The increase of multitude in proportion to the decrease of magnitude, operates as a principal cause in enabling the blood to purify itself from its concomitant serum (n. 203, 204), to divide itself into more simple blood, and to elevate itself into a higher sphere, order, and virtue, for the sake of performing its more universal circle. When arrived here, it still further multiplies itself and its causes; and in the highest sphere, its number is almost ineffable and unassignable, this being the sphere of as it were the universality of its particularities.\*

214. *And finally, in the subordination of vessels of one degree to vessels of another degree.* (n. 67, 137, 138, 141, 146, 148, *seqq.*)

215. *Whence the certitude of the effect is ensured.* For a branch will be nowhere bereft of its blood, and die of emptiness, since although the current were anywhere intercepted, still there are innumerable others which would flow to it, and the more innumerable in proportion as they conspire to a more universal end: thus in the brains they are more innumerable than in the body; in man than in brutes; in the organs and members which more directly minister to the soul, than in the others. Such is the manner in which the certitude of effects is ensured.

216. *And the several causes operate in repairing whatever deficiency or waste had taken place in the things severally caused.* The manner in which the cause flows in to accomplish its effect in the animal kingdom, is a subject of the profoundest enquiry. It is a mystery of nature which can never be revealed without a right understanding of the subordination of things, nor can this subordination itself be understood without a general experimental knowledge, and more particularly an anatomical knowledge of the brain and the body, where nature dwells in her own veriest science and art, her own magnificent palæstrum and theatre of disport. In this manner alone can one link be fitted to another, and a chain be completed sufficiently strong to bear the weight of the argument. We cannot therefore enter upon this extensive subject without applying ourselves to the knowledge of *causes* in general, and being led to perceive that they are internal and external: that *internal causes* are those which

\* In the highest sphere every particular is a universal.—(*Tr.*)



are in the superior degree, and that they are so called in relation to those which are in an inferior degree: that *external causes* are so called in relation to those which are in a superior degree; so that causality has relation primarily to forces and substances of a superior and inferior degree. For when the spirituous fluid acts upon the motive fibre of a vessel, muscle, or gland, it acts from an internal cause; when the red blood acts on the same motive fibre, it acts from an external cause; when however the purer blood acts, it is from a cause which is external in relation to the spirituous fluid, and internal in relation to the red blood, so that the purer blood is in the intermediate cause. A similar observation applies to all parallel cases. Internal causes therefore proceed from a fountain which is comparatively universal, pure, perfect, prior, and superior: external causes proceed from a fountain which in its nature is the reverse of the former. But in this article enough has been said on the subject of causes, inasmuch as it enables us to see to a certain extent, that causes repair the deficiency and waste which had been occasioned in the things caused, and that this cannot be accomplished without the subordination of vessels of one degree to vessels of a higher degree.

217. *Moreover, in order that the brains may be continually producing this effect by the agency of their own causes and first principles, and also lest, through continuity of communication, they should be affected by any vitiated states of the body, both the arteries and veins which are proper to the body, and also those which are proper to the brains, form communications with each other in a manner peculiar to themselves.* The arteries of the brains are the internal carotid and the vertebral; the internal carotid is properly the artery of the cerebrum; the vertebral is properly the artery of the cerebellum, the medulla oblongata, and the medulla spinalis, inasmuch as it is reflected into the anterior and posterior spinal arteries. All the other arteries, however numerous, belong to the rest of the body. It is worth our while to enquire in what manner the arteries of the brain and those of the body communicate with each other, because we may thence infer the nature of the influx by which one acts upon or into the other, through the medium solely of the blood. This however is a subject reserved for another Part, and

more particularly for that on the Brain ; still as we are here speaking of appetencies and aversions, of those causes of general pressure which alter the equilibrium and the circulation, as well as of the means used in repairing any loss or deficiency in the things caused, we are under the necessity of so extending our present argument as to include this subject. We shall refer to it, however, only in a cursory manner, inasmuch as in the sequel we shall have occasion to treat of the arteries, veins, and motion of the brain, separately and distinctly. We learn from anatomy, that the carotid artery, on entering the cavity of the cranium, emancipates itself from the influence of the heart or the body, and places itself under the government of the brain alone as its sole moving power ; for, 1. The whole carotic stem ascends not as a trunk, but as a branch, of the aorta. “From the upper part of the arch [of the aorta],” says Heister, (and Ruysch\* asserts the same thing,) “in the human subject, most commonly three large branches ascend ; the right branch then divides, more or less remotely from the trunk, into the right subclavian and right carotid artery, &c. . . . Hence the aorta cannot be divided into an ascending and descending trunk. But in dogs, calves, and various other beasts, only one large ascending branch is generally observed, and from this circumstance the error mentioned above [namely, of dividing the aorta into an ascending and descending trunk] appears to have arisen” (n. 120). 2. As soon as this common branch arrives near the threshold of the cranium, it divides in a remarkable manner into an external and internal branch ; the external branch is distributed to the external parts of the head, the internal parts of the bones, and especially to the face and the organs of the external senses ; the internal branch enters the cranium through the foramen proper to it, in company with the intercostal nerve. 3. It leaves behind its muscular tunic at the porch of ingress, beyond the limits of which tunic the heart of the body is unable to act (n. 182—186) : for the artery when deprived of this coat no longer has the character of a continued heart, neither does it promote the circulation or propagate the wave. 4. It presently winds into numerous gyres, as if it seemed in

\* *Epist.* iii.—(*Tr.*)



this manner to wish to shake off the yoke of the heart. This is first observable in the osseous foramen itself. It is again observable when it has entered the hollow of the cranium; again as it descends into the receptacula cavernosa\* (as they are called by Vieussens<sup>x</sup>); again while it is sojourning in this region; and again when having perforated the dura mater it climbs the brain. 5. Not only does the artery divest itself of the muscular tunic, but it places itself under the control of the intercostal nerve, (which in the body is in lieu of the cerebellum and medulla spinalis,) and everywhere at the same time under the control of the dura mater; nor do these release it from their power and deliver it up to that of the brain, until it mounts the hemispheres of the brain, under whose control it thenceforward is. 6. In certain animals, it splits almost entirely into little twigs; these it surrounds with membranous prolongations derived from the dura mater, nor does it again form a junction with the trunk except at the base of the brain. 7. Having at length reached the cerebrum it ramifies and disseminates itself around in such a manner that there is no portion of the blood, either in the trunk, in any branch, or in any single offset, which is not common to all the others. 8. Thus ramified it finally extends itself to every individual spherule of the cortical substance, which it circumvests and constructs in a wonderful manner out of the inmost or last and most universal membrane of the arteries of the body (n. 145, 187, 188); hence the whole of that substance is pronounced by Ruysch to be vascular. (*Thes. Anat. i., ass. iii., n. 19, et passim.*) That such is the case, is seen from the resolution of the cortical substance by frequent immersion in water, and from the connections between the parts, as delineated by the above excellent authority. 9. This substance is, by means of the same membrane, continued into the fibres, and thence again descends into the vessels of the body, where it terminates its wonderful gyre (n. 151—154). 10. Thus those arteries which properly belong to the body, and those which properly belong to the brain, maintain with each other a communication peculiar to themselves; the arteries of the brain depending upon those of the body only so

\* “Receptacula sellæ equinæ lateribus apposita.” Vieussens, *Neurographia*, lib. i., cap. ii., p. 7, 31.—(*Tr.*)

far as is necessary to enable them to receive their due proportion of blood, although even in this case the quantity and quality of the blood thus received is left to the decision of the brains, into whose guardianship the body is committed. 11. In brute animals, however, the case is different. Indeed so great is the difference, that merely from a comparison of the determination of the arteries, it is clear, that animals are as much under the rule of their body as of their brains; which is the reason that they never cease to desire whatever their blood craves, and that according to the various changes and incitements experienced by their blood, they are led by blind instinct alone to the performance of the actions proper to them. In man, however, an entirely different communication takes place; a communication manifestly of such a nature as to be able to ward off the blood and detain it at a distance from the cortical substances, lest while the rational mind is occupied in revolving its reasons, the blood should too nearly approach, and interrupt its judgments, before the question is settled whether the will is to determine into act the appetencies excited by external causes, or those proceeding from the outward world through the external organs, and from the body through the medium of the blood. But of this we shall speak in Part II.

218. With a view to accomplish this end in the human frame, the arteries of the body and those of the brain are not governed by similar laws. For, 1. The arteries of the body push the blood from the heart to the extremities successively. All the arteries, however, of the brain are opened and shut simultaneously and at the same moment with the veins and sinuses. For there are as many animating corculi or little hearts as there are spherules of the cortical substance (n. 177), which require this simultaneous motion, because they animate simultaneously. 2. Thus the arteries of the body are dependent upon one great heart, but the arteries of the brain are dependent upon an infinite number of cortical and cineritious spherules, each of which regards the blood of every branch and twig as its own or as common to all, as we have already observed in n. 217. 3. When the arteries of the body extend themselves, they also in the same place are dilated; on the other hand, when the arteries of the brain are extended, they are also com-



pressed, and *vice versâ*. 4. The arteries of the body and those of the brain agree in this, that when the brain collapses, or compresses itself, its arteries distend, in the same manner as those of the body when the heart is in its systole; and *vice versâ*: &c. &c.

219. *And their motions are dependent upon different origins.* For instance, as we have just stated, the motion of the brain depends on the animation of the spherules of the cortical substance, and upon the consequent animation of the medullary substance. The motion of the body depends on the systole and diastole of its heart and arteries. For if the motion flowed from the same origin, and there were no causes to retard, suspend, and intercept its continuous action in its progress from one station to another, the determinations of the brain would necessarily arise from the motion of the body, and not the motion of the body from the determinations of the brain; consequently there would be no superior presiding over the inferior; no prior over the posterior; no more universal over the more particular; no more simple over the compound; no more perfect over the more imperfect; no interior over the exterior; no fibre over the sanguiferous vessel; no cause over the thing caused; nor any will over the action. Hence in accordance with our theorem, there would be no causes to repair any loss or waste occurring in the things caused, but the brains would by continuity be themselves affected by the vitiated states of the body.

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220. Hitherto I have been making only certain general observations on the fluxion of the blood and on its vessels, by way of explanation of the particulars of our induction. I now wish to moot certain minor questions on the mode and causes of this fluxion; questions which I abstained from introducing into the induction itself for fear of interrupting or obscuring the course of argument by too lengthy digressions, and which moreover are of such a nature that we cannot explain them except hypothetically, unless first provided with some general premises confirmed and demonstrated. These questions are as follow:

221. *By what method of nature is the process of secretion performed by the arteries?* There are, as is well known, secretory stamina, which issue and depend from their own little arteries. Now if into these the fibrated or nerveo-motive membrane of the artery (n. 138, 142), together with the inmost (n. 137, 187), be continued, it follows, that during the flux of the blood, each staminule is drawn, at every diastole and expansion of the artery, into the parent artery, and forms in the artery itself a larger excipulum or orifice, into which the serosity separated from the blood and ejected to the peripheries, enters (n. 199, IV.), while the blood itself is continuing its axillary course. When, however, the artery returns to its systole, or contracts, this orifice changes into a prominent little tube extending from its parent artery; the stamen being now relaxed; and hence the serosity projects itself out of it. The same operation takes place in all the other secernent vessels, and this continually. For if the fibrated membrane together with the inmost be continued into the secretory tufts, and if by the transflux of blood the artery be at the same time dilated and elongated, the effect produced, is, that the tufts draw themselves back into the expanded mater into which their tunics are continued, and immediately after, extending themselves, eject their contents. Hence the whole of the mechanism effecting the secretion depends on the circulation of the blood, and the circulation, upon the general equilibrium of pressure.

222. *By what method do the veins reabsorb the fluids which are conveyed to their stamina and orifices?* That there are stamina which depend from the little veins similar to those which depend from the little arteries, is a fact well known. Now if the fibrated, together with the inmost membrane of the little arteries, be continued into these stamina, but in an inverse order; that is to say, if the membrane which was the inmost of the artery becomes the outermost of the vein, and consequently also, as anatomists inform us, the outermost of the stamen which is extended from the vein; it follows, that at every diastole or expansion of the artery which is in continuity with its vein, the external membrane of the stamen so extended, is drawn upon; consequently the stamen itself opens with everted lips, and dips with open mouth in the passing stream. Again, when



the little artery is contracted or relaxed, then the stamen with convoluted and compressed lips draws its liquid into the vein, into which probably the stamen is entirely received, and discharges its milk. For if the inmost membrane of the artery become the outermost of the vein, then the mouth of the absorbitory stamen annexed to the vein is expanded and widened by the same force of circulation which straitens the secretory stamen of the artery; for while the artery acts upon the inmost membrane of its stamen, it acts at the same time upon the outermost membrane of the vein in continuity with it, and upon the outermost membrane of the stamen depending from the vein. Hence it follows, 1. That the artery expels its liquid, not at the same, but at the alternate moments in which the vein imbibes its liquid. 2. That the reabsorption of the liquid by the vein depends on the little artery, and hence on the circulation of the blood, while the circulation depends on the general equilibrium of pressure: that consequently on this equilibrium of pressure depends the whole of the natural chemistry; which cannot be performed without the continuation of the artery into the veins. 3. That inasmuch as the veins are passive, it cannot be predicated of them that they convey their own liquid into themselves, since this effect is continuous from the efficient cause of the artery. 4. That for this reason a vein does not send out its own reabsorbent vessels, but that these vessels insinuate themselves into the vein, and together with the artery constitute the vein. The first beginnings of a vein are thus the smallest vessels, and its end the right auricle of the heart, just as the end of the pulmonary veins is the left auricle of the heart.

223. *By what method does the arterial blood pass into the veins?* Let us suppose the case of a little interstice, where the inmost tunic of the artery is the only one, and which by a change of situation becomes the outermost tunic of the little vein. It will follow, that when the artery is contracted longitudinally and latitudinally, the outermost tunic of the vein being drawn upon, affords a free access and open channel to the blood, and immediately offers itself as a receptacle to the blood which has come from the arteries; thus the office of the vein is only to receive the wave which the artery projects into it, and

to act only from the motion which it receives from the artery. Consequently, when the blood is received by the vein, then as soon as the artery becomes relaxed, and the little vein remitted, the sanguineous wave which the vein has received commingles itself with the waves educed through the stamina; thus the little canal distends, and if its intumescence be relatively greater than that of the branch or the trunk, then, according to the law of the natural equation of fluids, this intumescence discharges itself over the valves, in order that the vein may acquire its equipoise of impletion; while on the other hand, the valves are immediately closed by the pressure of the wave, whenever there is in the branches a smaller quantity than in the trunks, proportionally to their capacity and faculty of extension.

224. From these remarks we may infer the reason for which no oleaceous, aqueous, and much less saline, angular, and spicular substances are transmitted by the smallest blood-vessel immediately into the veins, but only the blood which has pursued an axillary course along the artery, and which flexibly yields and softly applies itself to the acting tunic. Unless the other ingredients were rejected to the parietes of the vessel, and were received by the mouths and little lacunæ of the artery (n. 221), they would only, by reason of their uncongenial nature, wear and tear, prick and cut, its smooth and sensitive interior coat; or if accidentally intruded, in consequence of any of the secretories being obstructed, the little venous canal would check their advance by convulsive contractions; or having swallowed, would vomit them out again;\* otherwise a vessel so immoderately stretched and inflamed, would every time become the seat of a diminutive aneurism. For this reason it is, that in the region of the minutest arteries there occur so many circuitous windings and turnings, so many wonderful dances, observable by the microscope. Leeuwenhoek “sometimes saw a clot of blood concreted in a vessel and blocking it up, and then gradually the clot was perforated by the constant stroke or impulse of the advancing current, until at last it transmitted a thread-like stream through the middle of it, and in fact acted

\* Canaliculus talis crebro singultu illa castigaret et excuteret, seu deglutita revomeret.



as a tube inserted into the vessel" (n. 125). Such is the reason for which only the purer blood aims at entering by the common channel into the veins (n. 203).

225. *Innumerable species of fluids or humors may be formed and elaborated by the process of secretion alone.* According to Heister: "The fluids of the body are the following: chyle, milk, blood, serum, lymph, animal spirit, saliva, the mucus of the mouth, bile,—the liquor of the pancreas, stomach, intestines, œsophagus, brain, eyes, thorax, pericardium, abdomen, tunica vaginalis testis,—semen, the liquid of the prostate glands, the mucus of the nose, tonsils, joints, urethra, uterus, vagina, and Fallopian tubes,—the humor of the ova, and that in which the foetus swims, cerumen of the ears, urine, and sweat." (*Comp. Anat.*, n. 34.) In extracting solely from the blood and its serum so many and even more numerous humors, animal nature seems to proceed only by one course, or to adopt only one method; namely, at every circulation she rejects to the parietes or peripheries of its canal or artery the substances less adapted to fluency, while it contains the blood, with other homogeneous and apter elements, in the median or axillary line (n. 199, IV., 221). Hence it ejects the former through its secretory tubes, while it forwards the latter into the veins which are in continuity with the artery.

226. That such an incalculable number of different secretions may be produced from the blood, is clear from the following considerations. 1. That the blood in its progress through the largest and least artery, continually projects to its sides first the mixed heterogeneous, and next the mixed homogeneous substances. 2. That the blood divides itself, and ascends into vessels of the second order, where in like manner it eliminates from itself, thus divided, mixed heterogeneous and homogeneous substances. 3. That a similar process is carried on in the nerves (n. 157, 162). 4. That consequently at one point in the line of progression the secretion never perfectly resembles that which is carried on at another. 5. That much less must be the resemblance, when we consider that the blood of one viscus is never altogether like the blood of another. 6. That so large is the number of the genera and species of secretions meeting together from foreign sources, even in any one single gland, vesicle,

or cell, composed of vessels of a threefold order, or of the red and pellucid blood-vessels and fibres, that even this is sufficient for supplying the first principles for the concoction of any liquor. To this we may add, 7. That in the organs of their respective laboratories, as in the little serpentine bladders, pipes, and phials, or in the several receptacles and pores, one fluid is mixed up with another, two, three, four times, or oftener; as in the brains, mammæ, stomach, liver, and everywhere else; and this, in the order in which each proceeds, either in an inward or outward direction, to its own proper destination, as in the case of the testicles, prostate glands, urethra, &c. 8. That the fluids which are thus mixed, are again conducted through filters, and after being percolated and discriminated in different ways, are again united, till finally they are formed into some tincture, essence, spirit, menstruum, laudanum, extract, or other recondite substance which the animal polity requires for the supply of its necessities, uses, or contingent emergencies. One of these substances becomes excreted; another is reabsorbed by the little veins; a third is destined for the nutriment and renovation of textures; a fourth, for the preparation of a fluid which is to serve some use within the circle of its kingdom.

Nowhere does nature exhibit so wonderful an aspect as here, where she is in the exercise of all her art: where indeed, so wonderful are her operations, that to the contemplative mind scarcely anything is left but a feeling of unmingled astonishment. Here, almost as large a demand upon our faith is made by nature as by miracles themselves. Indeed, it seems as if, when proceeding from first principles through her several subordinations, there were no state\* through which she did not pass, or as if her path lay through all things. A right knowledge of this subject however can be attained only by a mastery of the sciences of anatomy and pathology; nor even then can it be considered complete without a thorough proficiency in the entire chemistry and physics of the world and its kingdoms.

227. While I have been dwelling on these stupendous mysteries of the animal kingdom, and endeavoring to reduce its particular and specific modes of operation to a few general

\* Et videtur tanquam nihil ei a principiis et per suos ordines progrediente invium dari.



heads, and these to one universal principle, the idea has offered itself, of *a certain equation of quantity and quality in the fluids*, pervading the system, and to which nature, as if for the sake of equilibrium, tends and aspires with all her might. But since in the body there is a perpetual loss and restitution of equilibrium and rest, and consequently, a change of equation; therefore, from this source results the diversity of the blood and the serum in the different viscera. For when more of one species of liquid is demanded, consumed, or eliminated, in one extreme than in another, a new liquid of the kind must immediately run thither to supply the want, from all parts, corners and provinces of the kingdom, near and remote: and this, by reason of the equation of quantity and quality, which nature has ordained throughout, for the sake, as we before said, of maintaining her equilibrium. Wherever, therefore, from any cause, an excess of one species is consumed, thither of course a supply of the same species must flow, from other parts, near, intermediate and remote: and with greater rapidity than to a part where little or none of this species is required. Thus where such fluid is rapidly supplied, the quantity appears great; where slowly, it appears small; when notwithstanding, the equation is maintained, modified by mere differences of celerity: on which account, there are many paths which lead thither, and which are so adapted, as to provide a more copious afflux, corresponding exactly to the efflux. This appears to be the reason why the blood full of the better substances of the kingdom, rises to the brains; why the blood full of its more worthless and outcast substances, goes to the kidneys and the gall-bladder; why the blood, dilute in the first instance, is loaded with substances in a graduated series, from the lips, the gums, the fauces and the œsophagus, all the way to the stomach and the intestines; why the spirit of the mother is emulged by the embryo; why the power of venery is increased by its exercise; why the breasts and teats overflow while the infant sucks; and why habit becomes second nature; with many other things, which proceed from this single, simple and universal source and law. But this is a subject requiring deep investigation; consequently, if it be laid down briefly, and not illustrated constantly by examples, and proved by a conti-

nual reference to facts, its details must appear for the most part entirely hypothetical (n. 9).

228. *The artery, the moment it is dilated, becomes also elongated or extended in both directions.* As for instance, when it is traversed by the wave, or held in distension by a more than usually large quantity of blood. This fact may be exhibited to the senses both of sight and touch, by removing an artery from the body, and then injecting liquid into it, or inserting in it either a cylinder or the finger. The cause of this circumstance is found to exist in the structure of the artery itself; for its muscular tunic is composed of multifold series and layers of motive rings, which are by the expansion of the vessel divaricated or mutually drawn apart from each other, so that when unfolded laterally they become unfolded also longitudinally; the inmost coat, which subtends and collects the rings, meanwhile moderating and defining the expansion and extension (n. 188). It is however to be observed, that *the artery, when pressing forward its blood towards its ramifications, contracts and almost closes itself against the antecedent volume, in order that it may detrude its other volume downwards*; for if the undulation traverses the arterial tube, we can assign no other cause of elevation in the solid or undulating vessel than we could in the fluid or water; namely, that the superior part, or that which has been traversed, falls in, or becomes closed, while the inferior part becomes opened and extended.

229. The means by which this divarication and separation are performed, it is not in our power in the absence of facts fully to explain; we may however presume, that there are little fibres or membranes interposed between the rings. Bidloo, indeed, in one of his tables represents "the . . . fascicles [as] superimposed one upon another, and connected together by means of villous fibrils" (n. 117). If this be granted, then we may suppose that while the circles are mutually receding from each other, and the several series unfolding, the ligaments probably revolve themselves from one circle to the right, and from the next which is joined to it, to the left, or perhaps they simply contract. This observation, however, I regard as merely hypothetical; the structure of the bronchia, trachea, and similar vessels, will enable us to throw better light upon the subject.



230. *Consequently, a muscle composed of motive fibres is necessarily constricted on the expulsion of arterial blood, and vice versâ.* For what obtains in the larger arteries, obtains also in the small ones endowed with a motive tunic (n. 138, 142). For if the motive fibre of a muscle be formed by blood-vessels, and if also in these the nervous fibre has its termination (n. 151, 152), it follows, that as soon as the nervous fibre acts upon its own vessel, the blood is expelled from it, and the muscle, which is a compound of its own motive fibres, grows pale, hard, and constricted; that it acts in the same degree and in the same place in which the nervous fibre acts; that it is restored to its previous state as soon as the fibre ceases to act, and the arterial blood attempts to rush in according to its general equilibrium of pressure or mode of circulation. This is the reason for which the *vis agendi* or force of acting fails the muscle, if either the artery or the nerve be cut, removed, compressed, emptied, or outworn and effete.

231. *The strength and life of the body lie in the arteries and in their blood. The contrary is the case with regard to the veins.* The degree of life in the body is just such as is the degree of circulation of the blood in the arteries, and the degree of circulation is just such as is that of the general equilibrium of pressure (n. 180, 181). The action of the muscle depends upon the circulation, upon the equilibrium of pressure, and consequently upon the arteries (n. 230). In the same manner, upon the circulation and equilibrium depends the whole of animal chemistry (n. 221, 222). The vein itself also, without strength derived from the artery, lies inert (n. 223), not being capable of activity but only of passivity (n. 190). So far therefore as the blood is contained in the arteries, and only a just proportion of it is transmitted into the veins, so far we live. But so far as the blood is not confined to the arteries, but is poured out unrestrictedly into the veins, so far we approach the state of death; thus when we are dying all the blood flies from the arteries into the veins. Every virtue, therefore, which restrains the arterial blood from flying into the veins, is an abode of life; as in the instance of heroic courage, in intrepidity, in the ambition of earning from society some merited token of distinction, or in other similar cases; in which we pass from a lower into a higher sphere of

life, and put on a certain species of immortality. On the other hand, we behold an image of death in that state which banishes the arterial blood and precipitates it into the veins; as in instances of timidity, terror, astonishment, powerless and dejected states of mind, or others of a like nature, which bring to an end the life of the blood, and hence the life of the body. From what we have stated, we may perceive how justly it may be said that one person lives more than another.

232. As I have here been treating of the strength and life of the arterial blood, I may, with the reader's permission, venture a little farther into some illustration of the nature of that heroic valor to which I have adverted. Genuine valor, then, is preceded and accompanied by no palpitation of the heart, no cold sweat, no defection of the senses, or drooping of the limbs; that is to say, there is no immoderate flux of blood into the veins; no half-dying with fright; no dread of death; but rather a presence of mind, a quick intellectual discernment, a strength of limb, a kind of frothing of the cheeks from their glands, and an evolution of glowing heat; that is to say, life is more in quantity and better in quality. For the arterial blood then vigorously acts upon the muscles and on the organic beginnings of the nerves, and suffers itself but sparingly to be transmitted into the venous repositories. This action of the arterial blood results from the imperative mandate of the soul, which aspires to the glory or pleasure anticipated from the achievement of general good to a society, and still more to a number of societies. This genuine valor we may observe illustrated in Charles XII., late King of Sweden, that hero of the north, who did not know what that was that others called fear; nor what that spurious valor and daring that is excited by inebriating draughts, for he never tasted any liquid but pure water: of him we may say, that he led a life more remote from death, and in fact lived more than other men. "What think you," says Cicero, "impelled C. Mucius Scævola to slay Porsenna, without having himself the least prospect of escape? What power supported Horatius Cocles to stand against all the enemy's host on the bridge alone? . . . What end was aimed at by those two bulwarks of the Punic war, Cneius and Publius Scipio, when they thought to have excluded the Carthaginian hosts solely by



the barrier of their own single persons? What was the aim of Africanus Major and Africanus Minor? Of Cato, likewise, who arose in the interval between these heroes? . . . Can we think they deemed anything in life worthy of attainment, but what appeared to be worthy of praise and true glory? . . . And can you, upon whom God, or so to speak, the mother of all things, even Nature herself, has bestowed a mind, than which nothing in creation is more exalted or divine,—can you, I say, so debase and prostrate your being, as to think there is no difference between yourself and the brutes?” (*Paradoxa ad Brutum*, par. i.)

233. The skill and foresight evinced by animal nature in securing strength and life to the muscles, by means of the retention of the arterial blood in its own proper vessels, even when the limbs and fleshy parts are exerting their utmost effort to express it out of the artery, will in its proper place appear, from the wonderful transmission of the arteries through osseous and membranous rings; from their application under the muscles and nerves; from their circumvolution through the same; and from many other mechanical contrivances, occurring in the arms, loins, thorax, and every other part of the body a hundred times over: although it seems to have escaped observation that such contrivances were made with a view to this purpose. In the Parts on the Brain we shall see, that in that organ there is a still more astonishing distribution of the blood, inasmuch as there we find scarcely any other vessels than arteries ramifying over its entire circuit; so that even all the fibres seem to assume the nature of arteries, while the veins are extremely few in number, and banished to the extremities of the hemispheres, beside the large sinuses of the dura mater. Not to mention innumerable other modes of complication, connection, and constraint, in order to admit of a communication of additional force to the imagination, and hence to the genius when on the stretch; or, in a word, in order that strength and life may be derived to the brains from the arteries.

234. I. *The smallest vessels are to be considered as placed in one extremity of the sanguineous system, and the heart in the other. These two have a mutual relation to each other through the larger arteries, as intermediates.* The first beginning of the pulmonary arteries is the right ventricle of the heart;

and the first beginning of all the arteries of the body is the left ventricle of the heart. The aorta therefore is situated the highest up, and is hence the first to emit the wave that the others receive, and successively forward to the ultimate vessels, which are the goals and boundaries of the circulating blood, and the offsprings of the one aorta. The heart therefore is situated at one extreme, the region of the capillaries at the other, and the two hold a mutual relation to each other through the arteries as intermediates; whatever therefore occurs in one extremity is perceived in the other through the intermediate arteries. II. *The region of the smallest vessels is that in which nature most especially exercises her powers and celebrates her animal sports.* For when nature is in that region, she is as it were left alone to herself, and is in her own palæstrum, where she is most perfectly free to act. For this reason it is that she has here compounded and disposed her motive fibres, and through the medium of the muscles exhibits to view her force of acting. In this region also she has arranged her secretory vessels, vesicles, and smallest cavities, and commences her course of animal chemistry; nor is she prepared for the performance of the least office in her economy before she comes into her pure first principles; she has therefore surrounded her heart with a similar region, or with an entire muscle, which while it is in one extreme, is also duly observant of the other, because it is compounded of the other. III. *These smallest vessels, or the whole of this region, are more immediately than the larger vessels dependent on the rule exercised by the brains.* For in this region the nervous fibre is in its simplicity, perfection, universality, and highest degree of presence, and proximately invests every vessel which it actuates as one which is immediately its own, or as itself in form; and since the vessel is here the vessel of the fibre, and the blood is the blood of the vessel, hence the blood is the blood of the fibre, and consequently the blood of the cerebrum and cerebellum, from which the fibre flows, at whose slightest intimation it is constrained to act; a truth which is very obvious from the influence of the will upon the muscles. Moreover, the most universal and the inmost membrane, which ultimately produces the veriest fibres as it were by a mode of derivation from itself, clothes the fibrated membrane of the vessel, and of its secreting and absorbing



stamina : whence the brains flow in and act upon the smallest vessels through the medium of a twofold arrangement ; that is to say, through the medium of this membrane, and also through the medium of the fibres. This is the reason for which nature has there located the veriest laboratories of her chemical art, and transcribed thither as it were the mind or *animus* of the brains. IV. *Hence it is, that the mutations are perpetual in this region of the smaller vessels, and are according to the various actions and affections of the brains.* There are hundreds, if not thousands, of these mutations within the space of a day or an hour ; for in these is the mind or *animus* of the brain, because the brain is the same in its ultimate as in its primary fibres ; for at one moment it is gently incandescent ; at another, it grows indignant ; at another, hot and angry ; at another, it is preyed upon by envy and hatred ; at others, it is merry, loves, lusts, simulates, saddens, grieves, and pines away ; at others, it elevates itself with hope, confidence, or daring ; and, in fine, troubles both itself and the whole of this region with a thousand little motions and initiations of affections ; which is the reason that there are here such a number of momentaneous fluxes and refluxes of blood, of currents and vortices, of openings and compressions, of waves tending forward into the veins and backward again out of them, of obstructions and perpetual local aneurisms ; so that unless the brains were constantly present, and as it were indwelling within them, they would, as often as they occur, plunge the whole system into anarchy and ruin. See n. 210—219. That the mutations here are thus perpetual, is shewn by the varieties of transpiration, exhalation, sweats, urine, and respiration ; by the varieties of color in the face and extremities ; by the varieties of pulse, states of health and disease ; by the proneness to the formation of tendinous substances, to consolidations, concretions, and innumerable other things ; so that in these perpetual mutations it appears as if there were an imitation of an atmosphere ; and as if in the body, particularly the human, there was nothing more constant than inconstancy ; and as if the cause of old age, disease, and death were perpetually in action. V. *Every one of these mutations, existing in the region of the smallest vessels or in one extremity, produces a corresponding result in the other extremity, or through the*

*medium of the intermediate arteries, in the pulse of the heart.* The variation of the pulse is not derived from these mutations only, since it arises not only from internal causes, or from the influx of the brains through the fibres into the smallest vessels of the heart and the body; but also from external causes, or from the temperature, heat, and sluggishness [*lentitudine*] of the blood; from polypous concretions, indurations, spurious and genuine aneurisms, and other accidental circumstances: the internal causes of which are excited by external things, or the external things by the internal causes; and whether it be from the former or from the latter, still when the smallest vessels are affected, the general equilibrium of pressure and circulation become affected, and hence also the pulse. But inasmuch as the doctrine of the pulse is that from which medical men derive the prognostications and symptoms of health and convalescence; and inasmuch as we cannot perfect this doctrine without traversing the circle of the anatomy and physiology both of mind and body; it is to be remembered that I have here anticipated the mention of only one, although the principal cause by which the blood is affected.

235. *In cases of inflamed parts and membranes, a more immediate remedy cannot be exhibited than that of opening the vein whose roots are derived from those parts. This is shewn by the phenomena of revulsion and derivation.* In the veins there is a simple impletion, and an equation of their blood, but no circulation such as exists in the arteries (n. 191—198.) The impletion of the veins, however, and the equation of their current, does not extend in a direction from the trunk to the branches, because there are little valves which prevent the reflux; they proceed consequently from the lowest radicles into the little twigs, thence into the branches still larger, and next into the largest (n. 205, 206, 222). Thus when a proper venous branch is laid open, the old, pernicious, sluggish, and obstructive humor and blood are perpetually separated, and the new arterial blood, from near and from far, is drawn by frequent beats and impulses into its own and into the clogged and inviscated venous vessels, together with a purer moisture supplied by the absorbent vessels (n. 222, 223.) Hence causes are enabled to operate for the restoration of such things as have fallen into dilapida-



tion (n. 216). It is however requisite that the branch which is opened should have its roots principally in the disordered viscus, and the discovery of this branch must depend upon our knowledge of anatomy. For certain kinds of inflammation in particular parts, a more immediate and seasonable remedy cannot be applied. The more common or general therefore be the vein which is opened, the more general and effectual will be the result; while on the other hand, the result will be less general and more tardy, if the vein which is opened be confined to a particular quarter. This is clearly and uniformly attested by the wonderful phenomena of revulsion and derivation; by the sudden mitigation of bad symptoms in cases of accident; by unexpected recoveries; by the effects produced in cases of pregnancy, &c.

236. *Much more blood is contained within the smallest vessels taken collectively, than is contained in the trunks; and from a variety of causes a larger quantity of blood is capable of being contained within them.* Ridley has remarked the same of the arteries of the brain. (*Anatomy of the Brain*, chap. iv.) For the areas of the orifices which open from any one trunk into the branches, are collectively much larger than the area of the cavity of the trunk. In the same manner the diameters of the smaller vessels collectively, exceed the diameter of the parent branch; and so on continually. It is the same with blood as with water; a large quantity derived from one common stream may be collected in the smaller streams which diverge from it. This is evinced by the fleshy substance of the muscles, the blood of which, when expressed, considerably exceeds the capacity of the aorta, considered exclusively of its branches. For the wave which at every systole is expelled from the heart, is not the same with that which is extruded through the ends of the arteries, but is the propagation of the undulation thus begun, which permeating all the ramuscles, urges the blood from them towards the veins which open from them. For when the muscular fibre is constricted, no blood can be transferred from its arteries into its corresponding veins, so long at least as the muscle remains in a state of constriction; on the contrary, it is transferred through the fibre of the antagonist muscle, then through the fibre of some other muscle, and so on. Hence

nevertheless a corresponding quantity of wave ejected from the heart is naturally expressed. This wave, however, is larger or smaller by reason of a variety of causes; consequently, also, there is a variation in the general equilibrium of pressure. The quantity is larger whenever the muscle fears or trembles; less, whenever it intrepidly, indignantly, or haughtily offers resistance and hardens itself (n. 231, 232, 233). A similar observation holds in all other cases.

237. *We cannot assign the exact quantity of red blood contained in the animal body, or the proportion it bears to the cohering solid or exsanguinous part.* Some calculate the quantity of blood contained in the body at 25 lbs. Others say that in a man there are only 8 or 10 lbs.; that in a sheep the weight of the blood to that of the body is as 2 to 22 (n. 127). But the quantity cannot be assigned, because the red blood is always in a state of reproduction and formation, as also of decay and destruction (n. 149, 151, 158, 199, VII.); and because there is no fluid in the body which did not preëxist in the blood (n. 59—61). The consequence is, we must assign to the red portion of the blood all that part, including even the whitest fluids, which is contained in the various vessels, little pores and lines, and the whole of that which is contained in the fibres, and cannot be expressed out of them by any art. If all this should be added to the red portion of the blood, we shall then have serous and spirituous blood, such as was contained in the heart and aortic trunk. In addition to this I may here observe, that one man is possessed of a much greater quantity of blood than another. For this reason, the quantity of blood in any animal, is the quantity of fluid it possesses in relation to the solid part, and which constitutes considerably the largest share. This very clearly appears from the large quantities of blood that have often been lost in hemorrhages from the nose. In one case 48 lbs. were lost in three days; in another case, 75 lbs. in twelve days: see the *Acta Lipsiensia* (n. 127).

238. *From what we have stated, the reason is clear for which the arterial so remarkably differs in its nature from the venous blood.* As for instance, that it is warmer, more brilliant, more florid, more coagulable. For in the veins the blood is in a state of formation (n. 151, 154, 201, 205); in the arteries it has al-



ready passed through a state of reformation. In the veins the blood is everywhere diffused, and one part is held in separation from another; in the arteries the blood is driven to the axillary line, so as to form as it were one fluent fibre (n. 199, IV.). In the veins the spirit and the serum are reunited to the blood; in the arteries they are disjoined, and the blood itself is divided. Hence arise its color, brightness, redness, coagulability, &c. The same is observable in the chick during its formation in the egg; for Malpighi relates, that “the blood propelled through the arteries was of a deep red color; but that which returned through the veins had a yellowish hue” (n. 242). The more common or general therefore be the artery, the more does its blood abound in foul heterogeneous elements, from which it is clarified in proportion as it is elevated into purer regions, or transferred beyond the branches leading into the kidneys, liver, and other viscera (n. 203).

239. *Finally, there is nothing in the whole mundane system more perfect than man, and yet nothing more imperfect if he abuses the faculties designed to be employed in making him perfect.* In general we may observe that man is an animal machine possessing a structure worthy of our highest admiration; he is a most marvellous complement to the whole mundane system; so marvellous, indeed, that all nature appears to have unfolded herself in him. In order the more to see how astonishing are his perfections, let me recall the attention of the reader to a few only of our preceding remarks. 1. How ingeniously in the human body is one thing subordinated to another; how is an imperfect part placed under the rule of a more perfect; for the vessels are subordinated to the fibres, the blood to the spirituous fluid, the body to the brains; while upon the brains are bestowed science and efficient power. 2. In man, all those things are multiplied which are more perfect, and which pertain to causes or first principles. For he has a larger brain, its divisions are more ordinate, and the fibres thence educed correspond in quantity and purity to the superior organization of the brain: by these fibres the contained fluid is so dispensed, that everything in the body is in subservience to them. 3. There is bestowed upon the brain a still more universal first principle.

and eminent faculty ; namely, the soul ; which is as it were a tutelar deity and demi-goddess presiding over her own little world ; and to which is assigned within the limits of that world a certain species of omnipresence, knowledge, power, and providence. The power, presence, knowledge, and providence, however, which are supreme, the Author of nature has reserved to himself ; and these He exercises upon such conditions, that so far as the corresponding faculties of man are dependent upon Him, so far are these faculties conducive to more perfect and universal ends. 4. When therefore the Author and Builder of all things graciously bestowed upon man a soul possessing the faculty of immortality, to this faculty he added that of reason, and to reason that of the will, and both will and reason he endowed with liberty. This he did, to the end that, contrary to what prevails in brutes, no external moving cause and incitement might flow into act, without a previous consultation of reason ; but that it might receive from reason a specific determination.

240. But, *fuimus Troes !* The time was when we were men ; now, alas, how are we fallen ! how are we daily continuing to fall ! The dignity of the soul we have degraded to the dust. We have set menials over her as her lords and masters. We have abandoned ourselves to the tyranny of the body, the blood, the world, or externally inciting causes ; for we are under the arbitrary control of pleasures and desires, by which we are hurried away to ends which are often contrary to the more universal, and to Him who is of all ends the most universal. In the whole world, therefore, there is nothing more imperfect than man in such a state ; as may be seen by comparing him with brutes ; for animals, when excited by external causes, are incapable of acting except in a manner suitable to the nature according to which they have been organized. Whilst man frequently both intends to act, and also does act, in a manner little suitable to his organization, and this, by the aid of a perverted reason.

Opposites mutually correspond to each other. One may be measured by the other : depth by height ; ill fortune by good fortune ; hatred by love ; grief by joy ; disappointment by



hope and ambition ; slavery by liberty ; imperfection by perfection. This imperfection we must in our present state measure by the degree in which we abuse the remaining faculties with which we were endowed for perfecting our nature, or the faculties of reason, will, and liberty.

### CHAPTER III.

#### ON THE FORMATION OF THE CHICK IN THE EGG, AND ON THE ARTERIES, VEINS, AND RUDIMENTS OF THE HEART.

241. BELLINI. "Malpighi . . . observes that there are many kinds of insects, including the silk-worm, that are not furnished with a single heart, but with a number of hearts longitudinally disposed through the body, and which are of the figure of olives, and open one into the other. He observes, moreover, that these hearts do not pulsate simultaneously, but successively one after another in their places; the motion of the first being followed by that of the second, and so on in consecutive order. Furthermore, that creatures of this kind do not possess compound or collective lungs, situated in a given part of the body, (as is the case with the human subject, and with numberless animals,) but that they have air canals distributed through the whole body and all its parts; . . . a most astonishing device, and at the first blush well nigh incredible. . . . These little creatures, with their many hearts and well aërated frames, are everywhere provided with exceedingly viscid liquids, which in fact adhere most tenaciously both to their particular organs and structures, and to their bodies generally, at the surface of which latter they either remain at rest or are carried off. Hence it is that these liquids can be thrown to [only] a short distance by any instrument of propulsion, more particularly if impediments occur in the course of the passage; for they are separated with the greatest difficulty from the surface of such instrument, and adhere with the greatest readiness to the surfaces of all objects in their way. . . . But since it is requisite that these little creatures should be recruited and nourished by liquids thus constituted and distributed, and since these liquids are fitted for their offices by admixtion with air, hence, precisely in the same manner as in consequence of their sluggish nature, they cannot be derived into a single heart, so for the same reason they



cannot be derived into any single collective lung, situated in a separate and distinct part of the system, &c. (*Opuscula Aliquot : De Motu Cordis*, prop. ix., p. 58, 59 ; 4to., Lugd. Bat., 1696.)

“Read Malpighi, and you will then understand how much the structure and motion of the heart and auricles differ at the commencement of generation, and for some days afterwards in the womb, from the structure and motion of the same heart and auricles after generation and out of the womb. But I will endeavor to explain this incredible subject in a few words, in order that the reader may understand the whole matter with less trouble than he must bestow in consulting the treatise of that author. Picture then to yourself a canal with a continuous cavity, but of unequal calibre or diameter in different parts; and suppose the wide parts or dilatations to be three in number, and the narrow to be four; then the whole length of the canal will be divided into seven parts, three of which are dilatations, and the other four contractions. The three dilatations, then, are elegantly arranged in the following manner : they do not succeed each other in direct sequence, but are each placed between two of the narrow parts, so that one end of the canal is constituted of one of the four narrow parts ; this part is succeeded by the first of the dilatations ; this, by the second of the narrow parts ; this, by the second of the dilatations ; this, by the third of the narrow parts ; this again, by the third of the dilatations ; the series being concluded by the fourth of the narrow parts, which constitutes the other end of the canal. Now what do you think these parts respectively represent ? The first of the narrow parts is the trunk of the vena cava ; the first of the dilatations is the right auricle. The second narrow portion, placed between the right auricle and the second of the dilatations, is a passage or meatus that conveys the blood from the right auricle into the second of the dilatations ; and this second of the dilatations is the right ventricle. The third of the narrow parts, coming after the right ventricle, is a passage or canal that conducts the blood from the second of the dilatations into the third ; and this third dilatation is the left ventricle. Finally, the fourth of the narrow portions, which concludes the series, is the trunk of the great artery. Is there anything in such a constitution of parts at all like the heart after generation and out of the womb ? Here the trunk of the vena cava and the trunk of the great artery are in the same canal ; the left ventricle, the right ventricle, and the right auricle, are in the same canal ; and as for the left auricle, it is wanting altogether. Moreover this canal is slightly curved in one portion. The blood is driven from the auricle into the right ventricle, and from the right ventricle immediately into the left, through the narrowed tube situated between the two. See

how different the appearance of the heart and the motion of the blood at the time of their generation, and for some days afterwards in the womb, from the form of the same heart, and the motion of the blood, after generation, and out of the womb! But diversities and prodigies do not end here. Before many hours have elapsed, the whole canal, as far as the little tube that constitutes the third of the narrow parts, becomes more bent, and is turned upon itself, so that the right and left ventricles mutually approximate, and in a short time come in contact, and the intermediate canal is closed by turning upon itself: and at the same time the right auricle approaches nearer to the top of the right ventricle until it comes in contact with it; and the little tube that constituted the second of the narrow parts, is obliterated. After this, the pulmonary artery and the pulmonary vein issue from their respective ventricles, and the pulmonary vein has its auricle affixed to it above the left ventricle. What an incomprehensible series of things is here! What incomparable industry! How truly divine a process of fabrication!" (*Ibid.*, prop. x., p. 65, 66.)

242. MALPIGHI thus writes on the formation of the chick in the egg. "*After 12 hours of incubation* the . . . parts became more\* distinctly observable in the enlarged cicatricula, which rising upwards was almost horizontal. Thus the follicle† [or sacculus enclosing the chick] having been ruptured, the latter came in sight with a large head and two rows of vertebræ, forming the rudiments of the carina: that is to say, a series of white orbicular sacculi representing these parts, or of vesicles contiguous to each other, extended downwards, and beset the stamina of the spinal marrow; and the first rudiments of the brain were likewise obscurely visible. . . *After 18 hours of incubation* the cicatricula presented no great alteration in structure, but occupied horizontally the apex of the egg. The chick, with a large head and oblong spine, the latter covered by the ruptured follicle, was immersed as heretofore in the colliquamentum, of which the quantity was now increased. . . *At the end of 24 hours*, . . . I thought I could detect the motion of the heart, although on this point I will not be certain. . . *When 36 hours had elapsed*, . . . the head was plainly seen, turgid with the usual vesicles, and also the rudiments of the wings, and the spinal marrow. . . *After 38 hours* the chick, increasing in size, possessed a large head with three vesicles situated in it; . . . and was surrounded by certain

\* Malpighi previously describes the appearance of the parts *after 6 hours of incubation*.—(*Tr.*)

† It is to be observed that in the following description Malpighi refers throughout to his plates, but his letters of reference are omitted by Swedenborg, the plates not being given in this work.—(*Tr.*)



coverings encompassing the whole tract of the spine, which latter was composed, as heretofore, of the round sacculi of the vertebræ. Above the origin of the wings, I now for the first time plainly saw the structure of the heart, which I had indeed sometimes thought I could detect previously; for the chick now being alive, a pulse was observable, and when this pulse ceased, a kind of dark line was at last traced. . . . The umbilical vessels were seen ramifying about in the circumference with varicose and reticulated twigs; but their production as far as the heart was not yet visible; for they were obscured by the supernatant colliquamentum or thick albumen. . . . *After 40 hours* . . . the head was curved; the vesicles of the brain were not so evident; the rudiments of the eyes appeared; the heart pulsated, receiving from the veins a rust-colored humor, and sometimes a humor of the color of sere vine-leaves.\* For the external border of the umbilical vessels was surrounded by a thick venous circle, which at its extremities . . . opened into the heart. . . . At first the motion of constriction observable by means of the humor driven through the veins, was evidently into the auricle; from this the expressed juice was propelled [through a narrowed tube] into the ample right ventricle, by the constriction of which it was again protruded into a continuous appendage, from which there was a direct passage into the aorta. The aorta sent upwards certain considerable branches to the head, and was continued downwards in the form of a trunk, which after dividing extended as far as the extremity of the carina. Toward the middle region it gave off the umbilical branches, which spent themselves by ramifying twigs in the circumference, forming a reticular plexus, such as we always see at the extremities of the rest of the blood-vessels. A very similar implication [or plexus] was observed about the venous vessel [or circle]; so that I still doubt whether it be a broad vessel, or a conglomerated reticular venous plexus. . . . I think, therefore, that these vesicles pulsating in succession, constitute a true heart, surrounded as they are (for I have more than once indistinctly seen it) with muscular fleshy portions that have not yet taken on opacity or redness. . . . It is very difficult to determine by actual observation, whether the existence of the blood precedes that of the before-mentioned heart, or *vice versâ*. For although a dark rust-colored humor is frequently seen in the outer extremities of the umbilical vessels previously to the heart becoming obvious to the senses, and it may seem probable that the heart is formed out of a curved and expanded vessel, to which fleshy portions, as it were hands, are fitted externally; yet nevertheless, since at that

\* Xerampelini.

time all the parts are so mucous, white and pellucid, that use what glasses we may we cannot see clearly into their structure ; and since, as may be remarked in insects, the structures of the most advanced periods of existence have their rudiments in the primordial state ; so I still find ground to doubt respecting [the priority of the blood to] the heart. But this much certainly is visible, that the blood or sanguineous matter does not possess from the commencement all those things that are afterwards found in it. For at first we see in the vessels a species of colliquamentum conveyed by little channels towards the foetus ; afterwards, by means of fermentation, a yellowish [*sub-vitellinus*] and rust-colored humor is produced, which ultimately becomes red, and in this last state is put in circulation by the heart. Hence inasmuch as successive changes in the sanguineous matter are evidenced by the addition of color to the blood, so it may reasonably be doubted whether, in like manner, the existence of the heart is not rendered evident by motion alone, and whether the heart, although quiescent, nevertheless may not have preëxisted, but in a motionless state, in consequence of its fleshy fibres not being yet formed. But it seems clear that the ichor, or matter above alluded to, which afterwards becomes red, exists antecedently to the motion of the heart ; but that the heart, as well as its motion, are antecedent to the rubefaction of the blood. . . . *After the lapse of 2 days, . . .* the little sac of the colliquamentum, or the amnion, which was full of a copious dark ichor, contained the chick, the vesicles whereof filled the curving head ; the saeculi of the vertebræ were still more apparent, forming longitudinal lines ; and the heart, pendulous on the outside of the thorax, beat with a triple pulse ; one part of it pulsating after another in succession : for the humor it received, and which was in some cases of a deeper rust-color, was sent by the vein through the auricle into the ventricles, and from the ventricles into the arteries, and lastly into the umbilical vessels. I often kept the chick, and dried the yolk underneath it, and the pulsation of the heart continued without intermission for a whole day. . . . The veins emptied themselves by their last branches into the auricle of the heart. I was very solicitous to discover what was the first perceptible form of the heart ; and so far as the blood that it contained enabled me to make it out, I have represented it in the accompanying figures (fig. 15, 15, 15, 15) : from which it appears, that the blood is constantly carried into the auricle by the veins running from the border [of the umbilical vessels], and is expressed by the auricle through a sometimes short intermediate canal into the right ventricle ; thence into the left ventricle, and thence again into the arteries, by which it is transmitted to the head on the one hand, and to the umbilical vessels on the



other. . . . *At the end of 2 days and 14 hours*, the chick, increasing in size in proportion to the time, was lying prone, with eurved head, in the colliquamentum. The vesicles of the brain were observed, supplied with blood-vessels, together with the rudiments of the eyes ; also the spinal marrow, running in a longitudinal line, and contained within the vertebræ. . . . Certain blood-vessels came from the heart, and passing towards the middle of the abdomen, produed the umbilical arteries and veins. . . . The blood was discharged into the auriele partly from the extreme border, and from the ascending and descending vein ; the auricle then, by its pulse, protruded it into the [right] ventricle, . . . and this, into the next ventricle, by which it was sent at last into the aorta, to be by it distributed to the head, to the surfaee of the body, and to the umbilieus. *At the end of 3 days*, I found the ehiek lying with its body eurved and turned upside down. In its head, beyond the eyes, there were five vesicles turgid with fluid, which represented the brain. . . . The position and form of these vesicles was as follows : at the top of the head there was one of considerable size, furnished with vessels, and in shape like a hemisphere, and which, on the subsequent days, was in a manner divided into two ; for which reason I am still in doubt whether it is to be regarded as one vesiele at first, or as two. In the oeciput there was a kind of triangular vesiele, but the deep region [*profundam partem*] of the sinciput was oceupied by an oval vesicle, elose to which were placed the other two, eompleting the five. . . . The construction of the heart was as I have here given it ; for the mystery of nature, on which I before touched, was elearly resolved in the eourse of this day : the auriele reeeiving the blood from the veins, pulsated with a kind of double motion, as though distinguished into two chambers, and thus the blood was propelled into the heart in a peculiar way, which requires further investigation. . . . *At the end of the 4th day*, the chick had become more distinctly visible : the brain was proportionably very large, and the five vesicles constituting it were still more eonspieuous, and had come nearer together, and when lacerated, let out an ichor or fluid. . . . The round bodies [or saceuli] representing the vertebræ were increasingly protuberant. . . . The course of the vena cava and aorta within the body was coneaeled, and the little cord of the umbilieal vessels issued from the abdomen ; the blood propelled through the arteries was of a deep red eolor, but that which returned through the veins had a yellowish hue. Inside [the body] the rudiment of the liver . . . was apparent. In some instances the heart was pendulous on the outside of the thorax, and its aurieles, brought nearer to it, reeeived the blood from the veins, and supplied it to the ventrieles ; for the right ventricle had now attained its usual figure, and was connected immediately to the

left, which growing broader and larger, (and the beginning of the aorta being at the same time retracted,) by degrees assumed its own proper form. In some eggs that advanced more quickly, the cavity of the thorax was closed by a thin tunic, the heart being concealed within it, and the left ventricle hung downwards and lay upon the right. *On the completion of the 6th day* (see fig. 19), the chick was lying in the amnion; its head proportionably very large, and the great cerebral vesicle in a manner double, divided [from before to behind] by an oblong fissure, and affording perhaps a place for the falx, and when lacerated no fluid now escaped. The two anterior vesicles of the brain, less protuberant than before, were somewhat obscured by the incipient growth of flesh, and the rudiment of the beak was appended to them; the vesicle [above and] between them [in the deep region of the sinciput], was almost lost to view, as was the case also with the fifth vesicle placed in the occiput. The spinal marrow, divided into two parts, and consolidated, extended longitudinally through the carina. . . . The umbilical vessels issuing [from the closed abdomen] were partly sent to the thin albumen surrounding the yolk and amnion, partly into the yolk itself; and the arteries, now diminished in calibre, were much smaller than the veins. In the abdomen the structure of the liver began more clearly to shew itself. . . . The heart, hidden within [the body], although in a mucous state, had two pulsating ventricles, from which depended the sinewy auricles, of enlarged dimensions and exerting a double motion, and also the colorless vessels. . . . *At the end of the 7th day*, . . . the head was large and considerable, and the brain had become more protuberant, and was contained in the usual coverings, on lacerating which, the ichor so lately fluid was found to have concreted into solid filaments, thereby forming the walls and cavities of the ventricles. Between the large eyes the beak gradually manifested itself. . . . The umbilical vessels, coming outwards, were elongated through the yolk and albumen. The heart, shut up within the thorax, . . . was composed of two ventricles, as it were contiguous sacculi, united together at their upper part, and with the body of the auricles placed upon the top of them; and there were two successive motions in the ventricles, and the same number in the auricles. The tubular portion, which by its pulsations propelled the blood received from the right ventricle onwards into the arteries, was drawn downwards, and now increased the capacity of the left ventricle; and both the ventricles were successively enswathed by spiral muscular fibres, connecting and encompassing them, and which constituted the fleshy portion of the heart. The auricles themselves were uneven and corrugated in consequence of the interlacing of their sinewy fibres, and constituted as it were a new



miniature heart with two distinct cavities, presenting appearances analogous to what are seen in the adult state. . . . *After the 8th day of incubation*, the chick meanwhile increasing in bulk, the head still retained its relative large size, and on opening it, the cerebral mass was found to be still more solid. For the hitherto separate vesicles were now united, and constituted two eminences, containing the ventricles, the thalamus or bed of the optic nerves, the cerebellum, and the commencement of the spinal marrow. . . . The heart pulsated in the usual manner, and lungs of a white color were seen to have sprung up beside it. *After the 12th day*, . . . the structure of the lungs was discernible, the little ribs were solidified, and the muscles spread over them externally. *When the 14th day* had passed, the chick was already nearly perfect. . . The heart was formed of united ventricles, and a number of arterial tubules, like fingers on a hand, and which previously were at a distance from the heart, were now attached to it immediately. The auricles were large and intensely red, and composed of a network or plaiting of sinewy fibres, in which meshes or interstices of different colors were perceptible." (*De Formatione Pulli in Ovo.*)

243. The same illustrious author having repeated his observations,\* makes the following statement respecting the incubated egg. "*At the end of 6 hours*, . . . the rudiments of the carina and head of the chick were seen as a zone,† swimming in a colliquamentum of a leaden color, which was bounded by a circle that served as a kind of dam. . . . *At the end of 12 hours*, . . . the carina, defined by white zones, exhibited the round capitulum or little head, and also for the first time, beyond its middle, the orbicular vesicles [or sacculi] of the vertebræ, situated at intervals on either side. . . . In other cicatriculæ thus incubated, . . . the carina of the chick was defined by a white zone, furnished with two processes indicating the rudiments of the head, and had the globules of the vertebræ attached to it at intervals as in the former case. *After the 18th hour*, . . . the following was the appearance of the carina: the head was defined by the white zone, as well as the tract of the spine with the sacculi of the vertebræ appended to it.

\* The treatise, *De Formatione Pulli in Ovo*, is dated February, 1672; the treatise, *De Ovo Incubato*," is dated October in the same year. The reader may consult with advantage Malpighi's *Opera Posthuma*, where in his Autobiography (pp. 109, 110, ed. Amsterdam, 1698) he gives a brief but interesting comment on both the above treatises.—(Tr.)

† Or rather, "as the zone C," for Malpighi refers throughout to the numerous plates with which his treatise is illustrated. It is to be observed that the word "zone" does not in this case imply a circular figure, but is used to represent a structure of various outline encompassing the central rudiments of the chick.—(Tr.)

Around the head and neck I more than once saw a growth of flesh, together with the rudiments of the wings. . . . I have often remarked, as a usual piece of nature's play, a motion present in the zones, by the coming and going of which, the areas and cavities of the carina were either enlarged or obliterated. *Towards the end of the 1st day*, the protuberance of the head was visible, [as represented in fig. 11], and by the mutual separation of the zones in the back, a concavity or groove was formed in the carina, thereby affording a place for the spinal marrow, which had the vesicles of the brain appended to it. . . . *The 1st day having passed*, . . . and the incubation meanwhile proceeding, the number of protuberances about the head was encreased; . . . a portion of the heart became visible, [projecting beyond the carina in the form of a hook;\*] and varicose vessels were seen running forth in the umbilical area, turgid with a pale yellowish ichor. *After 30 hours*, . . . the umbilical area was covered with varicose vessels, . . . the color of which was at first yellowish, but became subsequently dusky red. . . . In the head the eyes were visible, . . . the [two] zones, united together, formed various spaces or areas, and surrounded the five vesicles of the brain, and the continuous production of the spinal marrow. At the lower extremity of the carina, a dilated angular area afforded a place for the loose extended portion of the spinal marrow [*laxatæ medullæ*]; the sacculi of the vertebræ were in their places as before. At this time the heart was clearly discernible. . . . I am still in doubt as to the priority of the heart or the blood. . . . But thus much is clear, that the stamina of the carina are observed before incubation; and afterwards, in the course of incubation, that the vertebræ, and the rudiments of the brain and spinal marrow, together with the wings and the fleshy covering, are displayed to view, while the heart, the vessels, and the blood still lie concealed. But when the little streams appear in the umbilical area, it is probable that the heart also is appended to the carina, since I could certainly detect its structure before the *30th hour*. A long interval however elapses, during which the heart and vessels are pervaded by an ichor, which at one time is yellow, then rust-colored, and at last blood red. Whence I am inclined to my former conjecture, that the juice, the vessels, and the heart, perhaps preëxist, and are manifested by degrees, as we observe in the ova of trees.† . . . *About the 36th hour* of incubation, . . . the cicatricula exhibited the umbilical area

\* This appears to be an explanation of Swedenborg's. The heart, as Malpighi figures it, perhaps rather resembles a segment of the link of a chain than a hook.—(Tr.)

† Respecting the ova of trees, see Malpighi, *Anatome Plantarum*, p. 81; ed. Lond., fol., 1687.—(Tr.)



covered with vessels. . . . In the head the topmost vesicle was distended with a lead-colored ichor ; the other vesicles were generally smaller, and full of a pellucid fluid, and the spinal marrow continued from them was somewhat dilated inferiorly, just as we find it in the adult bird. The fleshy growth was considerable about [the upper part of the carina], and the heart projected slightly beyond [the other structures]. *After 40 hours* the twigs of the veins had become more evident in the cicatrícula, and commencing from the extreme border, passed by prolongations into the heart, and the umbilical vessels arising from the heart, and forming an angle, gave off reticular branches, among which as yet there were not always any distinct large offsets. . . . In the head the usual turgid vesicles were seen, representing the brain, and the first of them looked like [a ball of] glass, and seemed to float upon the others. The zone was narrowed or contracted, and as usual surrounded the brain and spinal marrow. The eyes were placed one on each side. The heart was turgid, and pulsated in the same manner and kept the same time as I have described elsewhere. . . . *After 2 days* . . . the chick . . . was furnished with vesicles representing the cerebrum ; to these was added the cerebellum, together with the spinal marrow, which was guarded by the zones. . . . Near the extremity of the carina the spinal marrow was enlarged, and expanded into an oval form. . . . The heart pulsated very distinctly. . . . *At the end of 3 days* . . . the heart had grown still larger, and the blood received by the auricle from the vein, was propelled through a duct into the right ventricle, and thence [through another duct] into the left ventricle, and at length into the arteries, from which it passed into the trunk [represented in fig. 32]. From this trunk proceeded the umbilical branches, which terminated in twigs at the border, forming a reticular plexus. . . . *After the 4th day* . . . the blood-vessels were large, and the veins, for the most part more capacious [than the arteries], occupied the border particularly with a large trunk, the blood running forth mixed with a yellowish humor. . . . The head was conspicuously large beyond the other members. For the cristate [cerebral] vesicle, which was seen to be divided into two parts, was filled with a cinereous and somewhat concrete substance : not far from thence, in the occiput, at some little depth, the second, or the vesicle of the cerebellum, was placed, and to it was subjoined a portion of the spinal marrow. In the anterior part, at a greater depth, lay the third vesicle, and the [other] two vesicles [completing the five] formed the termination or apex in front. . . . Not far from the head the heart protruded out of the open thorax, . . . its structure plainly consisting of muscular flesh. The umbilical vessels issued from the abdomen, and

the [umbilical] artery was more capacious [than the vein], and turgid with red blood, while the vein lay below the artery, was narrower than it, and contained a yellowish humor. . . . *At the end of the 5th day.* . . . the head was large, and the cristate [cerebral] vesicle was as represented in the figures [37 and 38], and replete with a filamentary substance : to this vesicle was attached the cerebellum. Anteriorly the two vesicles [of the apex] were seen, with the deeper vesicle placed above them. The eyes were visible, one on each side. . . . The thorax was open, and the heart was situated on its outside, composed of a right and left ventricle, and of an auricle placed upon the top of the ventricles. . . . *When the sixth day had elapsed,* . . . the same vesicular structure as heretofore was observed in the brain : the cristate vesicle was furnished with a large vessel, and the vesicle next to it was concealed, and could not be brought into view without denuding and separating the cerebrum. . . . The thorax was still open, and the heart visible ; the left ventricle drawn downward and dilated, lay upon its fellow ; the auricle being superextended. . . . *At the end of the seventh day* all the parts were more clearly developed. . . . The cristate vesicles [of the brain] were composed externally of a fibrous substance ; while their interior cavity was full of a fluid or ichor. . . . The cerebellum and the beginning of the spinal marrow were now solidified. The thorax was peaked or pointed, and the heart pulsated within it, covered with a slight pellicle. . . . The two ventricles were placed close to each other, and the left was the larger and redder, while of the auricles the right was the more capacious. . . . From this time till *the ninth day*, the viscera were rendered firmer, and the heart [now] presented its customary form. . . . *After the ninth day* . . . the cristate vesicles of the brain, which terminate in the origins of the optic nerves, were smaller and more deeply seated, and inclined to the sides ; and the same circumstances were observable in the anterior vesicles. At the base of the brain, which was now nearly solidified, the following appearances presented themselves. The anterior vesicles were seen, and likewise the origins of the optic nerves, running from the cristate vesicles to the eyes. A portion of the infundibulum produced from the contiguous vesicle, gave support and continuity to the brain ; and not far from this, the beginning of the spinal marrow was seen depending. . . . *On the completion of the fourteenth day,* . . . the lungs were discernible inside the body, and of a whitish color. . . . *On the following days,* all the parts increased in firmness. . . . The brain, now solidified, exhibited on its upper part the roots of the optic nerves of a diminished size, the anterior ventricles, the cerebellum, and the beginning of the spinal marrow ; and at the base, in ad-



dition to the parts just mentioned, the infundibulum was seen projecting." (*Appendix, repetitas auctasque de Ovo Incubato Observationes continens.*)

Such are the observations of Malpighi: but it is to be noted, that the *carina* is that small elongated space which contains the initiamment of the head, and the thread-like rudiment of the spinal marrow. This carina swims in the white zones, which latter proximately surround it, although they sometimes appear to be interrupted or discontinued at the top.\* But it is necessary that the reader should himself examine Malpighi's figures, and become familiar with the initial forms of the hearts of the chick, and with the singular inflections through which they pass in succession, before they coalesce into a single heart.

244. Inasmuch as some insects have a number of hearts, and these hearts are mere vesicles, and in simplicity of structure bear a certain resemblance to the primitive heart, it will, I think, be to our purpose, to cite the description of the heart of the silk-worm and butterfly as given by the same illustrious Author.

"The heart [of the silk-worm]," he observes, "is placed longitudinally in the back, between the . . . fibres of the muscles, and the lungs [or tracheal ramifications], which latter lie on each side; and it extends from the very top of the head to the farther extremity of the body, so that when the animal is alive, an obscure longitudinal pulsation of the heart is perceived externally. This heart consists of thin membranes, which are of the same color as the fluid they enclose, being at first transparent, but afterwards becoming yellow, and losing some portion of their clearness. Whether, in addition to membranes, the heart has, (as I am inclined to think,) fleshy fibres for performing its contractions, is a matter beyond the information of the senses. Its figure is extraordinary. In other living creatures the heart is a conical mass formed of spiral fleshy fibres,† but in the silk-worm and creatures of that class it is a single tube, continued from the tail to the head, and so far as I have been enabled to observe, with no dilatation or chamber at either end to originate its motions. . . . This tube is widened and narrowed at distinct intervals, and thus presents a number of oval dilatations continued one into the other; which . . . leads me to suspect that these dilatations are so many corcula or little hearts, reciprocally assisting each other. The number of these corcula is considerable, though I have not yet exactly determined it. . . . But it is probable . . . that there is one for each ring, or at any rate for each pair of lungs. . . .

\* See Malpighi, *Appendix de Ovo Incubato*, fig, 5, 6, 8—13, 17.—(Tr.)

† Ex fibris carnis in gyrum deductis.

When the hearts undergo systole, the lateral extremities of each advance to its middle, and assume a thickened or prominent appearance, but they do not come close together, for the middle portion of the heart lies between them, constituting a depression, at the sides of which they form two flaps or lines.\* But when the heart is in strong motion, these lines run together, and seem to overlap each other at its narrower part, in which case there is a rise or swelling at the middle of the heart. On the other hand, when the worm is dying, and the sides of the hearts are carried only a little and slowly towards the middle, there is then scarcely any perceptible rise in that situation. The motions of the hearts do not succeed each other at exactly the same intervals, but in silk-worms as well as in other [insects] the first motion of constriction sometimes begins in the last heart placed at the tail. Thus when the dilated portion is compressed, the thin humor contained therein is immediately extruded through the narrow portion into the next dilatation or heart, and so on; giving rise to a successive swelling, but which in a rapid diastole is too confused to be distinguishable. It becomes evident however when the insect is at the point of death, that the compressions are really successive, the vital humor being propelled from one heart to another, just as in other cases the blood is propelled from the auricle into the heart, and from the heart into the arteries. . . . Around the elongated heart, or rather around the several hearts the branches of the trachea creep and twine, so that its lesser offsets adhere closely by their terminal twigs to the membranes of the heart where they lie against the back, being there visible on account of the transparency of both the heart and its liquid. There is yet another body that besets the surface of the heart, and has offsets adhering to the latter on both sides; and furthermore, in the several grooves or incisures [between the rings], where the fleshy fibres terminate or are intercepted, this body exhibits new tranverse ramifications, so given off as to present almost the appearance of four right angles; from which circumstance we may infer, that two branches are also given off on each side in this situation by the corcula or hearts themselves. There are then a kind of mucous ramifications that surround the cardiac tube, by which the muscles also are covered, and the interstices in the viscera beautifully filled up; for indeed this body or substance is so abundant, that it more than equals in bulk all the other parts of the silk-worm, the whole cavity of the belly being pretty well filled with it alone. It is soft and tender, and so divided into oblong pieces or shoots, and so singularly involved, that however carefully examined, it is impossible to discover

\* Lineas paleares.



its real structure. In order to throw light upon this point, I have found it advisable to recur to the case of other insects analogous to the silk-worm. Thus in the larger caterpillars these white ramifications entirely cover the inside of the belly, and beset the viscera therein contained; and by taking a portion of them out, receiving it in water, and laying it upon a piece of glass, we shall obtain a rude notion of their course and structure. By this means we find, that they ramify in the manner of vessels, and inosculate with the branches next them similarly ramified, the whole series thus constituting a loose network. They are of an oblong shape, a little depressed, nor do they maintain a uniform breadth, but in some places are very narrow comparatively: in other parts they assume the form of leaves, then again become narrow, and ramifying like branches, inosculate and intertwine so as to form a loose network. . . . Before the fire this globose\* substance melts into oil and catches flame; wherefore the fatty globules contained in the reticular prolongations, as in membranous sacculi, may be likened to an omentum; and there is reason to doubt whether these are not granaries of fat, and whether by these means nature does not shew the great solicitude with which she gathers and holds this oily juice. These omental prolongations are supplied by minute tracheal pipes, which strengthen them throughout their course. (*Dissertatio Epistolica de Bombyce*, p. 15—17; fol., Londini, 1687.)

“In the butterfly [of the silk-worm] the heart has exactly the same structure as that above described, but the external color is different, and the motion inverse, for the coats of the several hearts are now thickened, and exchange their transparency for a yellowish hue; the heart being therefore more conspicuous in the butterfly than in the worm. And the motion of the hearts acquired during the first days of [the existence of] the aurelia [or chrysalis], still continues; that is to say, the juice is expressed from above downwards, and propelled by successive systole. But nature is by no means so constant in the above direction but that it may be altered by even a slight cause; perhaps indeed nothing can be less constant: and in truth there are so many contingent anomalies in this motion of the hearts, that I may be permitted briefly to give an account of those which I have most frequently observed. I remember having remarked in the butterfly a motion of the heart (rarely met with) from below upwards; and then, very shortly afterwards, the starting-places were changed, and the motion was directed from above downwards, and lasted a long time. In another

\* Malpighi previously says, in a sentence omitted by Swedenborg, that he discovered that the above substance had a globular composition.—(*Tr.*)

case, the heart exhibited a motion toward the extremity of the body ; the diastole of the upper hearts occurred but seldom, that of the lower hearts was quick and frequent, and that of the middle hearts again occurred only at long intervals : in this instance the pulse at last continued about the head alone, the other hearts being at rest, and the motion was wavy, directed from below upwards. In the butterfly likewise\* the heart began to pulsate at the lower part, and the pulsation extended upwards toward the head ; and if while this was the case the cardiac pipe was cut across, then the lower section exhibited a motion from below to above, which motion was exceedingly rapid at the bottom of the pipe, and comparatively slow and infrequent higher up : but on the other hand, the upper section pulsated the contrary way. In other examples, after making the same section, both the divided parts first contracted towards the head, and afterwards towards the tail ; the contained ichor being expressed at each pulsation. In the silk-worm again, just before it passed into the chrysalis state, the motion of the heart, previous to the opening of the belly, was directed from below upwards, but after the opening, the point of departure was changed, and 70 pulsations ensued, freely traversing the entire line of the hearts : yet gradually the motion regained its first direction from the tail to the head, and at last on slightly drawing apart [the parietes of] the lower heart with the nails, the movement from above downwards was revived. Very often after death a variety of motions are displayed by these numerous inter-communicating hearts : thus in some single one, three pulsations may take place ; in that next to it, only one pulsation, or perhaps two : and the motions are various even in the same heart ; for if one portion of a heart be inclined to the side, it manifests very rapid and frequent pulsations, as it were a tremor, while the rest of it, which has not been disturbed in position, beats as usual. When the insect is at the point of death, the motion does not always keep one rhythm, but sometimes is exceedingly frequent, at other times observes long intervals, and is extinguished in this manner, but reappears when the heart is wetted with water or saliva. To conclude what I have to say on this subject, I will here give an account of two observations which I was fortunate enough to make ; . . . the first in the heart of the caterpillar or worm commonly called *pinu*. In this worm, the hearts or corcula, opening one into the other, began their movements from below upwards, as I have constantly observed to be the case in all similar insects I have had to examine. Their coats were transparent, and slightly tinted with the color of the subjacent membranes. Meanwhile these corcula were con-

\* Malpighi has before stated that this is the case in the worm.—( *Tr.* )



stricted in rapid succession both in an upward and downward direction, so that the contained ichor fluctuated under the stroke of these various motions; and two globules of fat, adhering to each other and slightly immersed in the humor contained within the cavity of the heart, were tossed to and fro, presenting a singular spectacle. These globules then, when the humor in which they swam was expressed by the systole of the heart, were driven from below upwards, and frequently returned with force; but when they happened to stop in the broader part of one of the hearts, the supervening systole struck them with a most rapid upward motion, and made them ascend through more than three of the other hearts; while on the other hand, as often as they happened to lodge in the narrow part, they were generally squeezed toward the tail by the compression of the systole. Not seldom during the pulsation of the hearts, these globules exhibited a whirling motion, and sometimes even rapidly fluctuated without making any considerable movement either way. The second observation I made in the chrysalis immediately after it had been formed. The motions of the hearts were directed from the head to the lower part; then from the latter to the middle; from which the fluid was sent back by propulsion the opposite way, like a hand-ball, to the tail; and this game of nature lasted in this manner for no inconsiderable time, until two motions, directed to the opposite ends, burst forth from the middle, upwards and downwards: and at last a single motion was left, namely, from above to below." (*Ibid.*, p. 38, 39.)

245. LANCISI. "*After 6 or 7 hours of incubation*, the cicatrix clearly displayed the carina with the rudiments of the chick and the umbilical vessels, and also with the circle bounding the colliquamentum. *After 12 hours*, the head of the chick appeared in the carina, and the nodes of the vertebræ. *After 22 hours*, more or less, the umbilical vessels were increasingly conspicuous. *At the end of 28 hours*, I discovered the heart itself at the side of the spine, presenting the appearance and form of a varicose and semicircular tubule, but it as yet exhibited no sensible motion. *After 34 hours*, I saw the præcordia\* still more clearly, consisting not only of the foregoing semilunar vessel, but also of certain fibres, which began to be loosely collected [*advolvi*] around it. These remarks may suffice for the more rudimentary structure of the heart and vessels, previous to the appearance of any sensible

\* *Præcordia* is a word used in different senses by different authors: Lancisi explains that he "embraces under the term, the heart itself, the pericardium, the great vessels and the muscles to which the heart and pericardium are connected." (*Op. Cit.*, lib. i., sec. i., prop. i.)—(*Tr.*)

motion: I will now state in detail the more internal and beautiful relations that are usually seen in what is called the punctum saliens *after 40 hours of incubation*. . . . With regard to the quality of the fluid that slowly traverses the umbilical vessels toward the end of the second day, it is first yellowish, then rust-red, and at last sanguine or blood-red; whence it is very clear that the more fluid cylinders of colliquamentum, which appear pellucid and perfectly limpid before and on the first day of incubation, rise through certain gradations of color, yellowish and rusty red, before they attain the character of blood; these changes being brought about by a gentle fermentation caused by the warmth, and by the elasticity of the air in motion, the sulphurous particles meanwhile being disengaged by degrees, and the saline volatile particles raised [to the surface]. With regard to the structure of the heart, I may observe, that as soon as this organ begins to exhibit motion, and to deserve the name of a punctum saliens, it presents a most beautiful spectacle, but far different from what we find in the perfect chick, and in fully formed viviparous animals. Thus it is not of a conical figure until after the 7th day. *At the end of the 2nd day*, the rudiment of the heart is seen as a crooked, continuous, yet irregularly constricted and dilated vessel, which beginning from the junction of the umbilical veins, or from the vena cava, is first dilated into an oval vesicle, which is afterwards to become the right auricle; it is then a little constricted as it goes to constitute the right ventricle, which forms a second dilated vesicle; after which the canal is narrowed, and then again widened into a third oblong and large vesicle, which ends by becoming the left ventricle: this in its turn opens into the continuous and proportionably narrow trunk of the great artery, which here and there divides into various branches, but more particularly into two, which ultimately form the umbilical arteries. These terminate in a reticular plexus at the circumference of the cicatrix, and the umbilical veins there begin and constitute an orbit of motion in the blood of the foetus, running from the circumference through the veins to the præcordia, and from the præcordia through the arteries to the circumference. But during the time when this rudimentary form and structure are seen in the heart, or rather in the three hearts or corcula represented by the three oval vesicles, the heart itself is not protected by the usual coverings, nor is the breast fortified and enclosed by the ribs and sternum, but it lies open, and the corcula hang out of it, and present themselves to view under the form of a bent canal of unequal calibre, the sections of which are not as yet combined into one, nor in contact with each other. . . . With respect to the motion and rhythm exhibited in the constriction and dilatation of the corculum or



punctum saliens, when still appearing as an irregularly twisted and enlarged vessel, I can only say that the whole matter is astonishing. For on the third, fourth, fifth, and sixth days, not one, but two salient points or corcula are visible, one being the right auricle, which is the first to beat, the other consisting of the two ventricles, which rise and pulsate after the auricle. Moreover, it is worthy of remark, that as soon as the motion of the corculum begins, certain fine purpurascant lines (which prove to be the umbilical vessels) are traced from the border, or from the circumference of the colliquamentum in this situation, (as we said above,) to the centre of the cicatricula, where they terminate, and becoming enlarged form those vesicles, which are alternately filled, elevated and reddened by the influent blood; in other words, undergo diastole; and on the other hand, when the blood is propelled by them, are depressed and contracted, or perform a systole, during which action they become invisible, and vanish away. In this successive and alternate distraction and contraction both of the right auricle and of the ventricles (although it is extremely difficult to try experiments in so minute a field of observation), we sometimes, as a matter of curiosity, have observed that these motions are presently inverted, if the right or left ventricle be slightly pricked with a needle: and the same may be observed much more readily in the corcula of insects. . . .—*On the fifth day of incubation*, one may without difficulty see that the right ventricle of the heart has approached to the left, and is lying upon it, so that the two no longer appear separated, but conjoined and folded; and much more evidently so on the following days, when all the segments of the corculum are packed into one mass, and twisted together in their respective places so as to form a single cone. . . . The following circumstance likewise ought here I think to be mentioned; namely, that the motions of the auricles, which as I before said are observed to be alternate with those of the ventricles on the first days of incubation, appear to be successive rather than alternate after the heart has attained its conical form; for I saw the contraction of the whole corculum begin from the auricles indeed, and terminate in the ventricles, but I have not seen this action amount to a complete alternation. . . .—On the first days of incubation, the curved and irregularly dilated vessel that represents the heart, is furnished with no external fibres embracing or constricting it: but by degrees from the fifth to the seventh day, it is braced and strengthened by the development of a number of sinewy lines and bundles of fibres. The præcordia, which previously to the fourth day hang almost naked on the outside of the thorax, are on the fourth or fifth day covered over by a fine tunic, and gradually after the seventh day are concealed within the thorax, being enclosed

by the soft rudiments not only of the pericardium, but also of the pleura, ribs, and sternum. . . . While treating of the auricles, I must by no means omit to mention, that although the right auricle is already in being on the first days of incubation, it afterwards either becomes larger, or at least maintains its diameter; but the left, which by reason of the inflexion of the tube is later formed, is at this subsequent period of less diameter than the right." (*De Motu Cordis*, &c., prop. xxiv., xxv., xxvi.)

246. HARVEY. "I observed on several occasions, that after the heart itself, and even the right auricle, had left off beating, and were as it were *in articulo mortis*, there manifestly remained an obscure motion, and a kind of inundation and palpitation, in the blood itself that was contained in the right auricle. . . . A similar phenomenon, in the first generation of a living creature, is very evident in the hen's egg within seven day's after incubation. First of all there is in it a drop of blood, which palpitates, (as noticed by Aristotle); out of which drop, by progressive increments, as the chick becomes in some measure formed, the auricles of the heart are made, and so long as the auricles pulsate life continues. When a few days after the body begins to be defined, then also the body of the heart is framed, but for some time it appears white and bloodless like the rest of the chick, and shews neither pulse nor motion. In a human foetus, about the beginning of the third month, I have seen the heart similarly formed, but white and bloodless, although in the auricles there was an abundance of purple blood. And in the egg, when the chick was of some size, and had reached an advanced stage of formation, the heart began likewise to enlarge, and to have ventricles, by which to receive and transmit the blood. . . . There is room to doubt whether before [the heart and even the auricles pulsate] the blood itself, or the spirit, has not in it an obscure palpitation, such as I have seen continue after death. . . . I have observed that a heart really exists in almost all animals, and not only, as Aristotle says, in the larger species which have [red] blood, but also in the smaller, which are exsanguious; and in some of the crustaceous and testaceous animals, as snails, cockles; . . . nay, even in wasps, hornets, flies, &c." (*Exercitatio Anatomica de Motu Cordis*, cap. iv.)



#### INDUCTION.

247. IN the formation of the embryo in the womb, or the chick in the egg, all things are carried on most distinctly. And the several members are produced successively, or one after another: so that there is no real effigy of the greatest in the least, and in the germ no type of the future body,—no type which is simply expanded; for whatever coexists, must become extant successively.

All things, thus produced successively, are fashioned in anticipation of, and according to, the use they are afterwards to perform. Thus there is nothing but is a medium to some ulterior use and end, and as such, contains within itself the law of the several things that follow it, and refers itself to those that go before it, on which it depends, and for the sake of which it exists in its own distinctive manner.

There is a certain formative substance or force, that draws the thread from the first living point, and afterwards continues it to the last point of life. With respect to this formative substance or force, such is the defect of terms, that we can predicate scarcely anything adequate of it, except that it is the first, the most perfect, the most universal, and the most simple, of all the substances and forces of its kingdom: and that it has assigned to it, within its own little corporeal world, a certain species of omnipresence, power, knowledge, and providence. The first ends, as well as the middle and ultimate ends, accord-

ing to which causes follow in provisory\* and given order till they arrive at the ultimate effect, appear to be present to it and inherent within it simultaneously and instantly. Consequently this substance or force represents to itself the state about to be formed, just as if it were a state already formed; and indeed the state already formed as a state about to be formed. Moreover the series of all the contingents, in the order in which they successively appear for the purpose of completing the work of formation, is instantly present to it, and as it were involved within it: for in the egg and the womb, all things that can possibly be contingently present, are already present, provided and prepared.

According to the nature and state of this formative substance, and suitably to its intuition or representation, causes flow into their effects: as appears from the different forms of animals; from the imaginative force in pregnant females, causing corresponding marks on the little body of the embryo; and from the formation of the brains, or of the organism of the internal senses, as being different in different species of animals, and in different individuals of the same species. Whence it follows, that no condition of the organism is primarily the cause of the internal faculties, but that that formative force or substance is the cause, whose nature, and the image of whose representations, determines the form of all things in the body.

The veriest formative force and substance is the soul: next in the order of forces and substances, is the spirituous fluid; next, the purer blood; and next, the red blood; which last is thus as it were the corporeal soul of its own little world. Thus all these may be called formative substances and forces; that is

\* The terms *provido ordine* are in general rendered by those of *provisive order*. The term provisory is used in the sense of foreseeing and providing; foreseeing, because in the first use the others are foreseen; providing, because the consequent contingent is provided in relation to the antecedent.—(*Tr.*)



to say, each in its own degree ; while the one vital substance, which is the soul, presides and rules over all.

Since then all things are thus most nicely subordinated and coördinated, it follows, that the spirituous fluid is the first cause ; the purer blood, the second cause ; and the red blood, the third cause, or the effect of the former causes. Also that the purest fibrils are first produced ; then the vessels of the purer blood ; and lastly, the vessels of the red blood ; one of these orders preceding the other, and then, according as they are compounded, one acting with the other.

Consequently, as the living creature grows successively in the egg or the womb, it passes through four remarkable changes and diversities of state. The first, when by the mediation of the spirituous fluid, the initiaments of the two brains and medullæ are drawn and delineated. The second, when by the medium of the purer blood, the simple texture of the heart is provided. The third, when by the medium of the red blood the lungs are brought into existence. The fourth, when the lungs themselves begin to breathe the air, which happens after exclusion from the natal egg, or from the genital womb.

There are three general sources of motion, on which all the particular sources depend ; and these three are, the brains, the heart, and the lungs. The motion of the brains is called animation, and the action of the spirituous fluid depends upon it. The motion of the heart comprises systole and diastole, and on these the circulation of the blood depends. The motion of the lungs is called respiration ; on this the circulation of the purer blood principally depends. But since the purer blood is intermediate between the spirituous fluid and the red blood, therefore its circulation depends upon the motions of the brains as well as of the lungs.

During the formation of the chick or the embryo, and previous to exclusion from the egg or the womb, the animation of the brains is coincident with the systole and diastole of the

heart; but after the lungs are formed, and the chick or embryo is born, the animation of the brains dissociates itself from the motion of the heart, and conjoins itself with the respiration of the lungs. The animation of the brains, however, again conjoins itself with the motion of the heart, whenever, from various causes, the lungs cease to respire, while the heart continues to beat.

Moreover, the primitive fabric of the heart, and the character of the pulse, in those animals that have one heart, and also in those that have many hearts, all conspire to shew, that the primitive corculum with its three distinct vesicles, in the nature and mode of its action resembles both the veins and the arteries, between which these vesicles are intermediate; that is to say, that an intermediary receptacle discriminated into three oval vesicles, is the result of vessels of dissimilar nature and mode meeting together. Furthermore, the simple fabric of the primitive corculum reveals the state that is ultimately intended for the adult heart and arteries.

But these things take place with a difference according to the perfection or imperfection of the animals in which they occur: also according as the animals are formed in the womb, or are formed in the egg. All the circumstances here recorded are most plain proofs of an infinite and omnipotent divine Providence.

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248. *In the formation of the embryo in the womb, or the chick in the egg, all things are carried on most distinctly.* What can be seemingly more indistinct, watery, and formless, than the carina or rudiment of the chick in the egg? Is it not like an unshapen molecule or miniature chaos? And yet nothing can be really more distinct. This is evident the moment that nature begins from this cicatrix to evolve the several parts in their order, and afterwards to reduce them into members, and cir-



cumscribe them with given boundaries ; for what before appeared to the eye a blank undigested mass, is now seen to involve the most perfect order and accurate discrimination. The very least irregularity occurring in the initiaments, or in the origin and progression of the first stamina, would give rise to great irregularity in the course of their progress, and to the greatest possible in the ultimate product. It would be as though an arrow or ball were shot at some distant mark, with an error of only two or three minutes of a degree in the aim, in which case the farther the ball or arrow had to fly, the farther it would be at last from the target. The least insensible deviation at first, ultimately ensures a considerable error, it may be of many degrees, or even of an entire segment of a circle. The reason for which in this first rudiment or living point nature acts with such prodigious distinctiveness, is, that in proportion as she is raised through her degrees, she attains to the perfection of all qualities, faculties, and powers ; nor is she ever really left to herself, and to her own forces, until she has arrived in the field of her purer conditions.

249. *And the several members are produced successively, or one after another : so that there is no real effigy of the greatest in the least, and in the germ no type of the future body,—no type which is simply expanded.* That is to say, using the common expression, there is no mere extension of the seed ; for independently of the cicatrix, not a shadow of the future body is at first apparent. The carina exists in and from the cicatrix, and the zone extends around the carina, the colliquamentum being bounded by the zone. Then the rudiments of the head and dorsal spine are developed, and afterwards, beside the spine, the corculum or little heart, no trace of which is visible till after a day's incubation. All the other viscera succeed each other in their own proper order. The lungs do not make their appearance till the tenth or eleventh day ; from which it would seem as if the little cerebella had decreed not to adjoin the lungs to the corculum, until, after a few days incubation, they find an atmosphere present, which they can draw in alternately, for the purpose of prolonging life subsequently to leaving the shell. After this the lungs are walled in by the ribs. In like manner with regard to the other organs : they all exist and are acquired successively,

each in its own proper time and sequence. The first and succeeding elements of the composition of these organs, lie diffused throughout the whole of the albumen and yolk of the egg, from which they are elicited each in its own order, and by wonderful mazes conducted to this living centre, and to the circumferences thereof. Neither is the expansion of the corculum, or of any other member, a simple expansion; that is to say, there is no type or effigy of the greatest in the least. For at first the heart consists of three vesicles, one of which succeeds the other; and in order to be made to assume the effigy of the greatest, it is wonderfully contorted during many days, and one vessel rolled up beside another. Hence it is only at a late period, and when about to form the lungs as appendages, that it knots together to form the ventricles, and places the auricles upon the ventricles. In a word, if we glance through the entire process of formation, as unfolded and described by Malpighi and Lancisi, we shall not find any two members developed simultaneously, nor the effigy of any member in its smallest form to be the same with that of its largest and most expanded form; nor anything simply swelling and enlarging, and preserving the same shape throughout its progression. A similar succession of things takes place in the chick, not only while within the shell, or in the embryo while in the womb, but in each also after birth. Thus the wings come successively, the feathers from the wings, and the quills from both. The female breasts, which are at first concealed, become protuberant: then the lactiferous vessels shew themselves, and finally yield milk for the nourishment of the infant. The ram marvels at his sprouting horns; the cow at the dewlap hanging down from her neck; the elephant at his lengthening proboscis; the peacock at the growth of his starry tail; not to mention similar things with regard to innumerable other animals, for enough has been said to shew that all things are successive, that is to say, are put forward in successive order, as signs of some future tissue, viscus, and connection of parts.

250. *For whatever coexists, must become extant successively.* For the cause must exist before the thing caused, the efficient before the compound; the engraver before the seal, and the seal before the impression; the prior before the posterior, and the



universal before the particular. Thus all things take place by degrees and moments, into which also nature herself is introduced the instant she is introduced into her world; such being the will of the Deity. Therefore, before anything is coördinated, it must be subordinated: which shews the truth of what we said above (n. 67), namely, that the rational mind, in analytically tracing out causes from their effects, nowhere finds them, except in the subordination of things, and in the coördination of things subordinate. For this reason we must mount through orders and degrees, in order to pass from the sphere of effects into the sphere of causes.

251. *All things, thus produced successively, are fashioned in anticipation of, and according to, the use they are afterwards to perform.* The first stamen or initia ment of the spinal marrow is drawn from the cicatricula, thus producing the carina, obviously with a view to the further use and end of enabling stamina to be given off therefrom for developing the lineaments and tissue of the future heart and the other viscera. The vessels stand around with varicose and reticulated twigs, and dare not yet approach their heart; obviously with a view to this end and use, that they may have run through all the stages of preparation, and be fully worthy to unite with the heart when its texture is sufficiently formed to enable it to bear their fluid volume. The little heart itself wonderfully twines, twists, and folds together its vesicles, as beautifully shewn in Malpighi's figures; obviously with a view to this end and use, that it may fitly apply itself to the coming lungs, into whose pipes it designs to bring the blood, and from these again to receive it. Hence the whole of this stupendous metamorphosis of the simple heart takes place on account of the lungs, to whose peculiar mode of coöperation the heart is finally adapted. After this the lungs are delicately traced and delineated in relation to every use they are designed ultimately to fulfil when they open to take in their atmosphere; and afterwards again they are supported on all sides by the ribs, sternum and diaphragm, beneath which the stomach, intestines, mesentery, kidneys, bladder, &c., are constructed. All these are sealed\* and lined with mem-

\* A simile derived from the chemical implements then in use.—(Tr.)

branes and muscles ; and drained by glands, vesicles and pervious lines. All are thus fashioned according to their uses ; so that in the whole of this progression there is nothing that does not regard some use as present, for the sake and on the model of which it is created. Thus the eye is created to and for its use, namely, sight ; the ear, to its use, namely, hearing ; the tongue, to taste and speech ; the nostrils, to smell ; the cerebrum, to and for the understanding. That is to say, all things are created in anticipation of, but yet to and for their uses. The womb, Fallopian tubes, ovaries, and other parts are produced long before the nuptial years ; likewise the breasts and teats ; which become alive with wonder when their time comes, and from a touch become presentient of the end for which they were designed. In the same manner the teeth are delineated ; and the beak, the hair, the feathers, the quills, with which the bird, after various attempts, raises his body into the air, so that before he flies he scarcely knows the use of the plummy paraphernalia with which he is accoutred. Thus is no creature aware by anticipation of the approach of ends, until it is actually in them. So the silk-worm is not aware that it has to be conducted by the silken thread of its inevitable fate into the chrysalis form, and that it has to leave the dark rhomboidal tomb where it is folded up, and mount upon wings into the air. How clear is it then that all the members, and all the appendages afterwards superadded to them, are so many instruments that are fabricated antecedently to the use for which they are destined when time reveals the secrets of their fate. But one member is never formed for its own use, unless at the same time for the general use of all its fellows ; aye, and of an innumerable order of successors which lie in it, and which occupy its regards as ulterior ends.

252. *Thus there is nothing but is a medium to some ulterior use and end, and as such, contains within itself the law of the several things that follow it, and refers itself to those that go before it, on which it depends, and for the sake of which it exists in its own distinctive manner.* There is nothing in the whole animal microcosm, nor indeed in the macrocosm, but is a relative and dependent being. The chain of subordination is perpetual ; there is always that which rules and that which obeys,



and all things are in some public office and function ; so that throughout there is the form of a kingdom, republic, and state. In order to arrive at a knowledge of the use of any member, we must contemplate its relation to all that go before, and all that come after it, and its dependence upon them, or the relation it maintains in the subordination of things. Otherwise, we shall not find how one thing is maintained in subservience to another ; how actions, for example, are under the power of the will, the will under the power of reason, and reason under the power of its own first principle ; how the body is under the influence of the muscles, the muscles under the influence of the fibres, the fibres under the influence of the brains, and the brains under the influence of their determining principle. The manner in which one thing regards another, and is itself reciprocally regarded by it, cannot be better explained than by the successive formation of the viscera and their several parts ; for that which is regarded by another, is prior to it, and that which regards the other, is posterior to it. One thing follows another according to the order in which the two are mutually related and dependent. Thus the little spinal marrow is dependent upon the primitive and incipient cerebrum and cerebellum. The heart is dependent upon both, arising as it does afterwards beside the little spine. The vessels are dependent on the heart, and previous to its motion stand around it, being kept as it were in waiting for it. On all these the lungs are dependent, because they arise subsequently to all. The little spinal marrow is formed with relation to all the viscera of the body ; the heart, with relation to the same viscera, which follow it ; yet so that it refers itself to the spinal marrow and the brains, and is dependent upon them. Thus all things are formed in their own order. The uses of all things, as I before said, are brought to light in this manner : the use of the heart, as dispensing the blood under the auspices and governance of its prior principles ; as commencing the circulation ; thus as providing for every part ; aye, and at the same time as subserving the brains ; which latter, out of the heart's blood, supply their fibres with spirituous fluid. In fine, there is nothing in the whole of this limited universe that does not contain the law of all that follows it, and at the same time refer itself to all that goes before it.

253. *There is a certain formative substance or force, that draws the thread from the first living point, and afterwards continues it to the last point of life.* This is called by some the plastic force, and the Archæus; by others, simply nature in action; but I think it will be more intelligible if in reference to the work of formation we term it the formative force and substance. For that which forms and as it were creates the little body, is not anything without it, but something within it; since before it can commence and proceed, something must preëxist in the ovum, and be carried into the ovarium. The same law obtains in the most minute and imperfect animals; the same in the larger animals; and the same in man, or in the most perfect of all. A certain formative force or substance must preëxist and be present while the embryo is formed in the womb, or the chick in the egg, in order that all things may be carried on most distinctly (n. 248), and in order that the several members may be produced successively, or one after another (n. 249). By which force and substance all things thus produced successively, are fashioned in anticipation of, and according to, the use they are afterwards to perform (n. 251); and from which and for the sake of which they exist in their own distinctive manner (n. 252). And which also in no other manner represents to itself the state about to be formed than as if it were a state already formed; nor indeed the state already formed than as a state about to be formed, &c. (n. 261).

254. That this force and substance is the same that draws the first thread, and afterwards continues it to the last point of life, follows from this, that a perpetual providence is exercised in continuing the thread once begun; or in other words, that the work of formation does not cease, but is still carried on, after the embryo is excluded from the womb, or the chick from the egg; for afterwards the animal enlarges and grows to maturity; the use of one viscus is obliterated, as of the succenturiate kidneys, the thymus gland, and other parts; the use of other viscera is brought out, as in females, of the breasts, the teats, the ovaries, &c.; and again of the teeth, the horns, the hair, and so forth; so that in the formed subject, formation and reformation still continue; and what is done in the womb is but the first projection of the woof, or the winding of the



slender thread round the spindle, in order subsequently that it may be wound off by degrees in producing the fabric. There are three sisters who manage these threads; to wit, the cerebrum, the cerebellum, and the medulla spinalis; each of which the formative substance empowers to act, and prescribes to each unalterable laws.

255. That a certain formative substance is preëxistent and present in these cases, is very clear from the extraordinary and unusual connection of parts, observable in foetal monsters. Thus some possess an undue number of arms, feet, fingers and toes; some are connected, in one way or another, by the belly, breast, spine, or head, with the corresponding parts of a second foetus; in some the vertebral column is curved like a plough-handle; in some the thorax is prominent and bulging; and the thoracic viscera are abnormally situated and abnormally formed; in some the neck is awry and inclined to the shoulder, and the head drawn down; so that the nerves, muscles, gullet, trachea, arteries and veins, are all distorted: others again are bandy-legged or bowed, and coördinate the forces of the muscles unnaturally, though in such a way that they can exactly balance even the weight of a club-foot; others have tumors, wens, hollows, and other malformations, by which the ginglymoid and arthrodial articulations, and the hinges of the bones, are frequently inverted. Not to specify further instances, where in twisted, broken, or dislocated members, the same formative force that existed in the ovum and womb, is instantaneously present, disposing anew the order of things with a view to the exercise of the members, and suggesting the manner of using them when thus disposed. Indeed to close my remarks on this topic, in no living subject do any of the several vessels, nerves, motive fibres and so forth, run through exactly the same courses; yet notwithstanding their differences in this respect, they all live in unanimity, and the life of all is suitable to the state. But if the reader will use his own powers, and follow up the rational investigation of the subject, he will surely conclude, that there is some formative substance and force, and that it is identical with that principle which repairs the dilapidations of the body, and when contingencies arise, renovates and perfects the system; and during formation makes one member

succeed another, or enables causes to restore whatever is deficient and decadent in causates (n. 216). Thus, according to our theorem, this force or substance is the same that draws the thread from the first living point, and continues it afterwards to the last point of life.

256. *With respect to this formative substance or force, such is the defect of terms, that we can predicate scarcely anything adequate of it.* For as it is the first substance of its kingdom, so it is also the most universal and perfect; and consequently in a manner above and beyond the sphere of common words and formulas. For in proportion as substances, and therewith forces, powers, modes and qualities, are exalted, they betake themselves into a higher and as it were different sphere, where they cannot be expressed by the same signs as before, as I have explained here and there in this Part (n. 264 [?], 270), and as the reader will find in Chap. VIII. This is the reason why ontologists are obliged to have recourse to analogies and transcendental terms [*eminentias*], in order to express these high powers of things; because a real entity of an inferior degree cannot be transferred to a superior degree by any process of attenuation or any kind of subtraction, but solely by the division of its parts or units (n. 158); wherefore it then changes its name as well as its appearance. If, therefore, we borrow words from an inferior degree to express any adjuncts of a superior degree, these words will hardly portray a single part of it: and if they are notwithstanding borrowed, then the points that they do not express must always be left to the further intuition of the reader, and be as it were understood; or else an attempt must be made to express them by stringing together thousands of formulas, and bringing out latent meanings by a thousand sleights of language: by which means books are distended with those equivocal terms that produce such hot dissension in the schools. Of this formative substance, therefore, scarcely anything can be predicated adequately, inasmuch as it occupies the supreme and superlative degree among the substances and forces of its kingdom: but I would rather call it a formative substance than call it nature; for it has within it a force and nature such as I have described.

257. *Except that it is the first, the most perfect, the most*



*universal, and the most simple, of all the substances and forces of its kingdom.* It is evidently the *first*, because it commences the thread, and when commenced continues it to the ultimate of life (n. 253). It is the *most perfect*, because it causes all things to proceed in the most distinct manner (n. 248) : and perfectly subordinates each severally, and when subordinated, coördinates them for their uses and ends (n. 252). It is the *most universal*, because it ensures the general good of all things, and at the same time the particular good. It is the *most simple*, because all other things in the body are successively compounded.

258. *And that it has assigned to it, within its own little corporeal world, a certain species of omnipresence, power, knowledge, and providence :—*of *omnipresence*, because it is the most universal substance, and in a manner the all in all of its kingdom ; for in forming all things, it must be everywhere present in order to form them. Of *power and knowledge* ; for it goes from principles to causes, from causes to means, from means to effects, from use to use, or from end to end, through the mysteries of all the mundane arts and sciences ; so that there is nothing, however internal and deeply involved therein, but it evokes it, and summons it to assist in building and completing its kingdom. In the animal kingdom, therefore, in whatever direction we turn our eyes, we meet with wonders that overwhelm us with astonishment ; so that it would seem that to this force or substance, starting from its principles and proceeding from order to order, no possible path were refused, but its course lay through all things. Of *providence*, for it arranges prospectively, that the members and parts of the members shall combine, and undergo renovation and formation, in one peculiar and contradistinctive manner (n. 261). We shall admit a certain providential series if we attentively contemplate the parts in the whole, and see how one is prepared for the sake of another ; how one always comes to the use of the next succeeding ; and how all, individually and collectively, are for the sake of the first substance ; since they refer themselves to their antecedents : hence all the consequents refer to the first of the series, on which they depend, and for the sake of which they exist in one distinctive manner (n. 252).

259. This formative substance or force then it is which

governs the sceptre and sits at the helm of the kingdom ; that is to say, marks out the provinces, disposes the guards, distributes the offices, and keeps everything in the station in which it has been placed, and thus takes care that everything shall execute its functions in all their details. Since therefore it is the most powerful, the most scientific, the most present, of all things in its body, it follows that it is as it were the demigoddess, tutelar deity, and genius of the microcosm. Nevertheless its power is extremely limited, although less limited than that of the substances and forces that come after it, in regard to which indeed it is comparatively unlimited. I say comparatively, for so far from being essentially unlimited, there is nothing possible to it but that which has been impressed upon and imparted to its nature ; so that its omnipresence, its power and providence, are almost entirely confined within the circle of its own narrow world. For the Author of Nature has reserved to himself the supremacy over it and all things, both in regard to power, presence, knowledge and providence, which supremacy he exercises according to the law, that so far as the soul is dependent upon him, so far it is perfect in every faculty, and conducted to universal and absolute ends, and its lower powers and degrees, by its means, are the same ; but so far as it ceases to be his image and likeness, so far it becomes imperfect in all its faculties, and lapses away from the nobler ends.\*

260. *The first ends, as well as the middle and ultimate ends, according to which causes follow in provisory and given order till they arrive at the ultimate effect, appear to be present to it, and inherent within it, simultaneously and instantly.* This follows from the law, that the antecedent is formed for the use of the consequent (n. 252) ; but there would be nothing conformable in the antecedent, unless this use or end had been before represented. Were not this the case, the rudimentary spinal marrow could not be adapted from the beginning to the conditions of all the members ; the heart could not be formed with a view to the conditions of the arteries and veins, nor yet with a view to the condition of subserving the lungs ; the lungs could not be constituted for the reception and expiration of their atmosphere ;

\* This sentence appears to be imperfect in the original : an attempt is here made to supply the sense.—(Tr.)



nor the trachea, fauces, tongue, teeth and lips, for the articulation of sound ; nor the eye for the enjoyment of sight, and by sight, of the universe ; nor the ear for the reception of tones. The same observation applies to all the other members, in each of which the use and end is always foreseen before it is actually present. To repeat my former comparison (n. 248), unless the archer take a right aim with his eye at first, the arrow at the end of its flight will be found vastly wide of the mark. But when distant and ultimate ends are kept in view as if they were present, intermediate ends are comprehended at once, and are carried onwards with a fixed aim and an unerring direction. Thus when the formative force or substance by a kind of intuition, if I may so speak, comprehends the ultimate end, then the intermediate ends are at the same time contained within it, extending to the end foreseen and pointed at ; that is, they flow in an unerring order.

I am aware, that in speaking of first and ultimate ends as simultaneously present and involved in the same substance and force, I am using terms that are not fully intelligible so long as we are ignorant of the mode in which they are present and involved. Yet I must have recourse to these terms, since scarcely anything adequate can be predicated of this force and substance (n. 256). For it is in the first principles of its things, and in a certain intuition of all ends, or representation of its universe. We cannot by any other means speak more adequately of it, since it lies beyond the sphere of common words, and of all such as are applied to the comprehension of the lower senses. But how the intuition of ends can accomplish such an effect,—how it can form a really connected and actually corporeal system,—this is not more easy to understand than is the manner in which the intuition of the mind, (which is also an intuition of ends,) is enabled to rouse all the muscles of the body to palpable motion, or in which a bare will is enabled to determine itself into real actions. Here we would only observe, that in this formative substance, ends are at once present and involved ; not that all things that can ever be in it are in it at once, but that they will be communicated to it, and thus are in it. We may fitly illustrate the case by an algebraic equation, which simultaneously comprises ratios, analogies and harmonies in

indefinite number, each of which may be successively educed and evolved, and again successively reduced into the same equation. And it will be seen in the sequel, that different ends may be present and involved in it, or the same ends in a different manner. This is true in the finite sphere. But in the Infinite Being, all things that can ever by possibility be involved, are involved at once; and this of themselves or essentially, and not successively. Of Him, therefore, change of state is never predicable, although it is predicable of all natural and finite things, and even of the formative substance itself.

261. *Consequently this substance or force represents to itself the state about to be formed, just as if it were a state already formed; and indeed the state already formed as a state about to be formed.* For if the ultimate ends are in it, together with the middle and first, then the state that has been formed is represented as present in the state that is to be formed, and the state that is to be formed in the state that has been formed; the one being involved with the other in momentaneous presence. The case is the same as when the mind embraces some ultimate object in its plans; for then it sees this object as if it were present, or when the means are furnished, contemplates it as already accomplished and realized: and how much more is this true in this higher faculty, where the principle of the mind's reason resides, or the force of forces, and the substance of substances.

That this substance represents to itself the state which is to be formed as already formed, is in some measure evident from the methodical distribution of the motive fibres in the body; so methodical indeed, that conformably to the slightest hint of the will, all things rush into effect. For the motive fibres are so fitly combined in the muscles, and the muscles in the body, that the mere nod and breath of the will is sufficient, in less than a moment, to excite and animate the associate ministers of action to the motion intended; that is to say, when this substance or force, for whose disposal they are thus prepared, determines from its principles. This we may see exemplified in the case of dancers, harlequins, buffoons, posture masters, athletes, harpers, songstresses, &c., whose lungs, trachea, larynx, tongue, mouth, fingers, eyes, features, feet, arms, chest and abdomen,



act in most stupendous concert ; not to mention other instances. Is there not here a representation of the thing formed, like as of the thing about to be formed, since the obedience of the whole is so ready and so easy ; into which obedience all that is formed naturally falls, by virtue of the same principle of action. For unless what is formed represented itself in what is to be formed, a similitude and concordance so great never could exist. And this is the reason why this substance, in the state of formation, always also persists in the thing formed, nor ever desists from this until the thread of life is broken. Wherefore the truth of the rule is evident, that subsistence is perpetual existence.

262. That this substance represents to itself the state formed as a state yet to be formed, is a consequence of the former truth ; for this substance is always in a state of formation and existence ; otherwise what is formed could not subsist. This is shewn in a lively instance in the case of parental love or storgē ; for parents regard their infants as themselves in the infants, or as most united other selves, and not as separate until long after birth : a sign, as it would seem, that the very force and substance that was in the parent, is transplanted into the offspring. If this be the case, then the same substance, always similar to itself, cannot act otherwise in that which is formed, than in that, namely, in the parent, which had previously been formed.

263. *Moreover the series of all the contingents, in the order in which they successively appear for the purpose of completing the work of formation, is instantly present to it, and as it were inherent within it.* Those things appear as contingent, which are successively to become present, in order that the process of formation may be rightly completed ; and which, if they were not present, would occasion the work to stop, and the connection to be broken and continued no further. Hence, when during the state of formation these contingents do not present themselves in their just proportion and rightful mode, the parts of the system are connected together in accordance with those contingents which are presented : as we see evidenced in monstrous births (n. 255). *For in the egg and the womb, all things that can possibly be contingently present, are already present, provided and prepared.* For everything that is wanted is involved in the albumen and yolk of the egg ; and this, with such

exactitude of arrangement, that each particular can be called forth and come in the proper order. The yolk also itself is distinct from the albumen, and within it lie the ingredients of the red blood. The like is the case in the womb, where the embryo draws from the mother's general store whatever its nature requires: thus it is provided and as it were foreseen that nothing in the chain or series of contingents shall by any chance be wanting. We may likewise instance parental love as a contingent, without which the slender and early thread of the infant frame could never be drawn out to the period of adult age. These things, I have said, appear as contingents, inasmuch as they must present themselves successively; but they are regarded as necessarily consequent, since they are present in the thing formed and thus are already provided. Thus one or the other of them being given, the effect cannot be otherwise than in conformity to it; for instance, warmth and fetus being given, other results present themselves of necessity. The same rule obtains in all other cases: for example, all the use of the heart is marked out before the heart is completed; and indeed by the little spinal marrow, before the heart appears. So likewise the lungs are designed in the heart, before the latter is doubled back upon itself into the form it is ultimately to assume. Successiveness gives an appearance as if use then first contingently began to determine itself to a consequent, when it is present in a previous organ already formed; but that the case is otherwise, is clear both from what I have here adduced, and from n. 260 and 261. So again it is provided that the ovulum be rolled down from the ovaries through the Fallopian tubes, the fimbriated extremities of which embrace and forward it, and that having reached the uterus, it should be surrounded with the membranes and liquor amnii; and by means of the placenta should emulge the blood: so that if only the contingent is provided, namely, the presence of the seed, all the other things necessarily follow.

264. Since all these things follow by inevitable connection, what shall we think of the fortuitous events, as they are called, that happen in civil life? It is not our province here to consider whether these are present and involved *à priori*, or not. At all events they are hidden from our view, just as the chry-



salis and butterfly states are hidden from the silk-worm, the process of formation from the embryo and chick, and the economic functions of the body from ourselves. Notwithstanding our ignorance in these respects, we are nevertheless constrained to admire the wonderful connection of ends within us, whenever they become revealed by the development of the ultimate end. But this matter cannot be fully explained, because the above are effects of the Divine Providence, and it is requisite that we should first enquire into the nature and effects of free-will.

265. *According to the nature and state of this formative substance, and suitably to its intuition or representation, causes flow into their effects.* That diversity and change of state are predicable of this substance, is a truth which I do not wish to prove by philosophical arguments, but by inductions derived from experience. I would here observe only, that everything natural and finite is capable of successively assuming different states, and when thus assumed, of holding them simultaneously: but I do not here propose to consider the quality of these states, but only to declare, that according to the nature and state of the formative substance, causes and effects flow conformably to the intuition or representation of ends.

266. *As appears from the different forms of animals.* To enumerate all the animals and their different forms, would require me to traverse ocean, earth and air. For there are aquatic, terrestrial and winged animals. Of each of these there are genera and species. There are moreover insects, multitudes of which elude the sight when unassisted by glasses. Of these insects there is as great a diversity as of the soils that produce, the leaves that nourish, and the sun-beams that vivify them. They have each their own proper form, and each their own proper formative substance. This formative substance constructs the effigy in accordance with the nature derived from the parent, rarely deviating from the model. Inasmuch as this is obvious to the senses, it remains only to conclude from these data the reason why forms are produced so dissimilar among themselves, and yet bearing such extreme resemblance to the one common parent. I ask, then, whether the rational mind can arrive at any other conclusion in this case, than that

there is a formative substance and force, which in conformity with its nature and state establishes such forms and laws of regimen as are suitable to the government proper to its kingdom; and that the body thus formed is an image of the representations of its soul?

267. *From the imaginative force in pregnant females, causing corresponding marks on the little body of the embryo.* For in case the mother experience any great alarm, or any inordinate emotions of terror or longing, and in this state the representation of anything be vividly made to her mind, it will immediately descend to the brains of the embryo through the vascular and fibrous passages, and (if I am not mistaken in the conjecture) through the innermost coat of the arteries and the outermost coat of the veins, and thence through the spirituous fluid and the purer blood. In this manner we find impressed upon the tender body of the embryo, figures of strawberries, cherries, plums, rape-seed; figs, apples, pomegranates, herbs, ears of corn, grapes, roses, parsley, lettuces, mushrooms, cauliflowers, finger-marks, weals, rods, flies, spiders; hence also arise dark-colored stains, fissured forehead, hare-lip, swine's snout; marks of fish, serpents, oysters, crab's-claws, bunching or webbed fingers, slugs, combs of cocks, mice, dormice, &c.: nay, further, from the continual contemplation of a beautiful person, the mother may superinduce the impression of a beautiful face, it may be her own or that of some other object of her admiration. The impression thus made does not disappear, but is permanent and continues to grow even during adolescence. Let us suppose now that the figure of a slug or dormouse was marked upon the cuticle of the foetus; that the cause of this phenomenon was some unsatisfied longing on the part of the mother, some emotion of terror or inordinate desire which had disturbed her brain; so that during the formation of the body of the embryo an impression corresponding with this emotion was made upon its tender substance: then from a consideration of these circumstances, let us proceed to infer the cause which operated in marking those members, and ask ourselves whether that which inscribed on the cuticle the effigy of the slug or dormouse was anything different from that which inscribes on the substance of the body the form of every successive viscus; whether, in



fact, it were anything but a seal impressing, whence arose a corresponding impression during a state of body in which everything yielded to the imprinting agent; that is, whether it were anything but causes flowing into their effects in a manner conformable to the superinduced representation.

268. *From the formation of the brains, or of the organism of the internal senses, as being different in different species of animals, and in different individuals of the same species.* This may be inferred from the external forms of animals, and also from the internal forms of the several viscera and parts. Of these we would select for example only the brains, where we find the organism of these senses. In some animals the brains are small, as in fowls and fish, and have no furrows and convolutions on the surface, but the membranes lie upon them in close contact; there is little or no cortical substance in the peripheries, but almost the whole of it is situated about the ventricles, and the thalami of the optic nerves are like two succenturiate cerebra, &c. Land animals and quadrupeds exhibit the greatest differences in the insulations of the brains; in the connection and formation of the ventricles, choroid plexus, glands, tubercles, infundibulum, and rete mirabile; in the influx and efflux of the blood; the organism being in fact altogether different. But in man the brain is more perfect and more capacious, and three times as large as even in the ox: more caution is shewn in the mode of distributing the blood through the arteries; not to mention innumerable other things, which are all so many evident proofs that causes flow into their effects according to the state and nature of the formative substance, or conformably to its intuition or representation.

269. *Whence it follows, that no condition of the organism is primarily the cause of the internal faculties, but that that formative force or substance is the cause, whose nature, and the image of whose representations, determines the form of all things in the body.* For such as is the formative force, such is the thing formed; such as is the seal, such is the impression; such as is the efficient, such is the effect; such as is the principle, such is the principiate; such as is the thing determining, such is the thing determined; hence such as is the formative force or soul, such is the brain and the body. For the body may not inaptly

be called the image of the soul; and so much is this the case, that from observing the face it is possible we may not always be wrong in our conjectures concerning the animal mind: but especially if we judge by a man's actions, which are mere executions of the will, and actual representations of the inner mind. This formative force therefore causes those creatures that have no intelligent or rational soul to be ignorantly impelled to ends by an instinct analogous to reason; while to those creatures, such as man, that have a rational soul, it has imparted a more capacious brain, a more spacious internal organism, and a more powerful faculty of using reason; and in this instance has prudently disposed its sanguineous allies under the control of the brain, and has prolonged the age in which reason may be cultivated so as to grow up to adult maturity. Hence no condition of the organism is primarily the cause of our enjoying reason; but the soul is the cause, which as an intelligent agent designing to enjoy the society of the inferior faculties, has so prearranged matters, that the avenues leading to herself may be properly disposed and duly laid open, or that all things in her kingdom may represent herself in an image. For this formative substance, inasmuch as it is comparatively eminent in situation, and is in the highest degree, cannot descend immediately to the mechanism of the body; for if there be three or four different degrees, the highest cannot act upon the lowest except through the intermediate. Hence it is, that when the organism of the intermediate degree is injured, or in any way affected, the soul cannot flow into the ultimate degree, or into the sphere of effects and actions, except in a manner conformable to the state of the intermediate degree. There are numerous contingents that may abrogate or alter the communication of the one with the other; for instance, when the brain is compressed in the womb of the mother; when it is flooded with blood or fluid that is not sufficiently purified, but has been disturbed by violent emotions, or by diseases; when the placenta has not been properly connected with the uterine folds; when the ovulum has not descended through the Fallopian tubes in proper time and order: with an infinite number of other circumstances, in all of which the formative force is under the necessity of combining the parts of the machine in a man-



ner different from what it otherwise would have done, and according to the series of contingents which has befallen it (n. 255, 263, 267). Besides, even after birth, accidents, wounds and diseases occur, which injure, affect and invert the natural state; frequently causing loss of memory, and of the power of exercising reason, also stupidity, stolidity, madness, fury, melancholy. None of these things however prevent the soul from remaining in a state of intelligence, although the intermediate organism, which has received from the before-mentioned casualties a different condition, cannot flow into the effects and actions of the ultimate degree except in such a way as is conformable to this condition. Thus we may understand how a soul as rational may reside in the tenderest infant, nay, in the idiot, as in the most consummate genius.

I have stated that the soul in irrational animals causes the animated body or animal to be ignorantly impelled to ends by an instinct analogous to reason. By natural instincts I mean all those operations which do not come within the consciousness of the mind, or to its intuitive knowledge or perception; such, for instance, as the economical and chemical operations of the animal kingdom, among which we may enumerate the systole of the heart and arteries; those laws of the commixtion, discrimination, separation, and elaboration of the blood which are recounted in n. 199; and an infinite number of other things which follow in their train. Of these operations the cerebellum appears to be the conductor, and it acts all at once or undividedly out of the Gordian knot of its structure, and moreover it is an organism of the second degree (n. 164). But not so the cerebrum, which is discriminated into innumerable cortical thalami, and its organism carried to the third degree of composition (n. 164), all the voluntary operations of the body being therefore under it. This formative substance is bound by necessity to adjoin the cerebellum to the cerebrum; so that the greater part of the economical functions and exercises of the body may be referred to the cerebellum, lest by any chance the cerebrum, when intent on its own concerns and reasons, should allow the republic to fall into inactivity and ruin, or distract and destroy it by insurrectionary motions, or by allurements and cupidities.

Since then all things in the body are adapted to the nature of the soul, and to the image of her representations, it is wisely provided that animals which possess no reason, and consequently no will, should live under the guidance of their instincts. I say no reason, and consequently no will, because will is a concomitant only of reason, and can be called will only in virtue of the liberty which results from reason. Animal instincts nevertheless so resemble reason, will and liberty, as those privileges exist in us, that nothing can simulate them better; nay, so well are they counterfeited, that we are all but deceived by the resemblance. Indeed, the actions resulting from instincts are truly marvellous, and seem as if they were determined by a species of deliberation and forethought, instead of proceeding from a blind impulse. In illustration of this we have only to refer to the different offices performed by instinct; as in the case of birds building their nests, laying and incubating eggs, excluding the young from the shell, nurturing their unfledged offspring, sending off their fledged offspring, giving warning of the season, selecting the food proper to them, distinguishing and dreading their enemies, eluding their pursuit, &c. In the case of spiders, weaving their ingenious webs under the tiles, setting traps for flies, and when captured coiling threads round the prisoners. In the case of bees, rifling the flowers, elaborating wax, storing their cells with honey, providing against winter, emigrating in swarms from their hives, stripping the drones of their wings, &c. In the case of the silk-worm, ensconcing itself in silken filaments, hiding itself until it assumes the chrysalis state, soaring next as a butterfly, and excluding its eggs with a view to continue the species: and what more may I not add in regard to other instances. All the outlines of the future body are traced by a similar instinct, in the egg and in the womb. Now if we resort to analysis, and reduce the known and unknown to an equation, and then evolve its proportions, do we not clearly perceive that there is a soul proper to every species of animal; that this soul adapts all things to the image and nature of itself; and that it cannot and ought not to construct the organism of the brains in brutes otherwise than that they may be governed by instincts in place of that reason and will by which man is distinguished. But I shall treat more distinctly



of this subject in the Parts on the Brain,\* where I speak of varieties of organism.

270. *The veriest formative force and substance is the soul.* For of the soul alone can we predicate that it is the most universal, the most perfect, the most simple, and the first of the substances and forces of its kingdom (n. 257) : that it is everywhere present, potent, conscious, and provident in its body (n. 258) : that it is the sole living substance, or that by which all other things in the system live : and that in its own kingdom it is the principle in every action ; and may claim the predicate of having momentarily present to it, and involved within it, both first, and middle, and ultimate ends (n. 260) : in a word, that in what is formed, and in what is to be formed, it is similar to itself ; being taken by derivation from the soul of the parent. That it has momentarily present to it, and as it were involved within it, the series of all contingents necessary for completing the work of formation (n. 263). That its power is so exalted that in all the public and private affairs of its kingdom, it can give its subjects laws from the throne of its simple will ; that it advances to the attainment of its purposes through the mysteries of all the natural sciences and arts, so that it meets with nothing so insuperable, but that in its descent from its principles down the ladder of order, it is enabled to arrive at length at the ultimate end which it had represented to itself (n. 258). Wherefore every action of the body is the soul's action, so far as it is an action of the will, this, an action of the reason, and this, of the principle of reason in which the soul is. But as the soul cannot descend without intermediates into the ultimate compositions and effects of its body, because the soul is in the highest degree, and cannot from the highest flow into the lowest and act upon it immediately, (for which reason there is a subordination and succession of things before there is any coördination and coexistence,) therefore it follows, that *next to the soul, in the order of forces and substances, is the spirituous fluid ; next, the purer blood ; and next, the red blood ; which last is thus as it were the corporeal soul of its own little*

\* See the *Animal Kingdom*, Appendix, vol. ii., p. 657, where there is some account by Dr. Svedbom of Swedenborg's extensive Treatise on the Brain.—(Tr.)

*world.* The red blood therefore, simultaneously comprising within itself the superior fluids, is the storehouse and seminary, the parent and nourisher of all parts of its kingdom, whether solid, soft, or fluid ; so that nothing exists in the body that did not preëxist in the blood (n. 59, 61). And on the nature, constitution, determination, and continuity of the blood depend the fortunes and condition of the animal life (n. 62). The blood is the ultimate fluid which discharges the functions of the soul in the animal kingdom (n. 46). See also n. 37—42, 91—99, 102, 133—137, 143—147, 154, &c. *Thus all these may be called formative substances and forces ; that is to say, each in its own degree ; while the one vital substance, which is the soul, presides and rules over all.*

271. *Since then all things are thus most nicely subordinated and coördinated, it follows, that the spirituous fluid is the first cause.* The first cause of all is indeed the soul, which is the life and spirit of the spirituous fluid ; and the determination of this fluid proceeds from the soul as its first principle ; but since through the defectiveness of terms, scarcely anything can be adequately predicated of the soul, we may consider this fluid, which in point of unanimity is the other self of the soul, as the first in the series of *agenda*. But how this fluid acts or forms from determining principles,—this is among the secrets of nature. For in the primordial state, as Malpighi relates, “all the parts are so mucous, white, and pellucid, that use what glasses we may we cannot see clearly into their structure. . . . But this much certainly is visible, that the blood or sanguineous matter does not possess from the commencement all those things that are afterwards found in it. For at first we see in the vessels a species of colliquamentum conveyed by little channels towards the fœtus ; afterwards, by means of fermentation, a yellowish and rust-colored humor is produced, which ultimately becomes red. . . . Hence . . . successive changes in the sanguineous matter are evidenced by the addition of color to the blood” (n. 242). From the whole process of the formation of the chick in the egg, as described by Malpighi and Lancisi, it is evident that these fluid substances act as the causes of things according to the beforementioned order ; as is clear from the first living point, the carina, the initia ment of the medulla spinalis, of the heart,



and other appended organs ; from the colliquamenta, zones, vesicles ; from the successive change of the liquids, and from the nature of the albumen and yolk in the egg. For when finally the red blood comes to be formed, and its assistance to be required, the vessels elongate till they reach the yolk, out of which the constituent, combining, and complementary elements of the blood are educed. They also so extend as to come in contact with the atmosphere (n. 50), since there are passages\* and commissures which lead through the shell of the egg, through the medium of which whatever the yolk may want is supplied by the air. That such is the succession and subordination of causes is acknowledged even by the most celebrated authors. Thus Lancisi observes, that “with regard to the quality of the fluid that slowly traverses the umbilical vessels toward the end of the second day, it is first yellowish, then rust-red, and at last sanguine or blood-red ; whence it is very clear that the more fluid cylinders of colliquamentum, which appear pellucid and perfectly limpid before and on the first day of incubation, rise through certain gradations of color, yellowish and rusty red, before they attain the character of blood ; these changes being brought about by a gentle fermentation caused by the warmth, and by the elasticity of the air in motion, the sulphurous particles meanwhile being disengaged by degrees, and the saline volatile particles raised [to the surface].” (n. 245). And Malpighi states, that the blood “ultimately becomes red, and in this last state is put in circulation by the heart” (n. 242). Consequently,

272. *That the purer blood is the second cause ; and the red blood, the third cause, or the effect of the former causes. Also that the purest fibrils are first produced ; then the vessels of the purer blood ; and lastly, the vessels of the red blood ; one of these orders preceding the other, and then, according as they are compounded, one acting with the other.* These positions are but mere consequences of what I have stated above on this subject in Chapters I. and II., and as it is not necessary to repeat the observations which are there made, I forbear saying more in the present article.

\* Cæci transitus.

273. *Consequently, as the living creature grows successively in the egg or the womb, it passes through four remarkable changes and diversities of state. The first, when by the mediation of the spirituous fluid, the initiaments of the two brains and medullæ are drawn and delineated.* There are as it were four different ages through which the animal that is to be formed has to pass, before it is fully in the ultimate world, into which it comes as soon as it is excluded and begins to breathe the terrestrial atmosphere, or to sensate the objects which are presented before, and contiguous to, its organs in the external universe. This is the first of the ages of innocence into which it is introduced. For the chick or embryo is now only a little stamen with a little head prefixed to it, connected together so as to form a sacred line. The whole is at this time surrounded and guarded by the colliquamenta and mucous zones, thus presenting the carina. The very stamen and first symptom of the future body, as soon as the vital warmth of the incubating mother begins as it were to breathe upon it, is roused into activity, and surrounded from top to bottom with a beautiful vesicular border, resembling a fine fringe or selvage. The vesicles convey a most purified essence elicited from the albumen through the imperceptible passages and meandering pores; while at the same time the proximate parts are wonderfully disposed with a view to contribute to the provided woof. These things occur within the space of a few hours, when there is not the slightest shadow of any viscus projecting beyond the rudiment. Malpighi describes this age as follows: "*At the end of 6 hours, . . . the rudiments of the carina and head of the chick were seen as a zone, swimming in a colliquamentum of a leaden color, which was bounded by a circle that served as a kind of dam. . . . At the end of 12 hours, . . . the carina, defined by white zones, exhibited the round capitulum or little head, and also for the first time, beyond its middle, the orbicular vesicles [or sacculi] of the vertebræ, situated at intervals on either side. . . . In other cicatriculæ thus incubated, . . . the carina of the chick was defined by a white zone, furnished with two processes indicating the rudiments of the head, and had the globules of the vertebræ attached to it at intervals as in the former case*" (n. 243). "*After 18 hours of incubation the cicatrix presented no great alteration in*



structure, but occupied horizontally the apex of the egg. The chick, with a large head and oblong spine, the latter covered by the ruptured follicle, was immersed as heretofore in the colliquamentum, of which the quantity was now increased" (n. 242). This, as I have said, is the first of its innocent ages,—an age in which the spirituous fluid traces out the first stamina with a view to form the little brains and medulla spinalis, from which all the other members are likewise formed. The mode, however, in which these parts are respectively delineated each from the time of its first inception, we shall endeavor to unfold in the Parts on the Brain and its Cortical and Medullary Substances. For every spherule of the cortical substance is a cerebellum in its smallest type, or is like a minimal brain, through which the spirituous fluid is conveyed, and from which once inchoated all other things flow in their proper sequence. Meanwhile this age is to be regarded as the first, or as the one in which the offspring first designs to visit the external world enjoyed by its parent, and by the rebirth of the parent in itself, to secure the immortality of its kind. The period that precedes, or that exists before it comes into the ovum or uterus, is not one that is proper to itself, but common also to its parent; and when from this it has passed into the periods and degrees proper to its own nature, then the mother represents to herself the offspring as still in herself, or as still existing in the period common to herself. This appears to be the reason why she does not regard her offspring as being as yet the object of that nurturing care and love, which is afterward the connecting bond between the two.

274. *The second, when by the medium of the purer blood, the simple texture of the heart is provided.* This state is the second of these ages of innocence into which the embryo enters, as soon as the brains have imparted sufficient length and continuity to the spinal marrow, and have thus laid a sufficiently solid foundation for the future edifice. After this all the operations continue to be carried on by the most regular laws; thus we find that in the next place there is nothing which the brains so much desire in the way of an associate and helpmate in their task, as blood and a heart. Consequently, the heart at length derives its origin from fibres rolled off from the elongated cicatricula,

as soon as the blood, standing outside, begins to redden. “*After 12 hours,*” says Lancisi, “the head of the chick appeared in the carina, and the nodes of the vertebræ. *After 22 hours,* more or less, the umbilical vessels were increasingly conspicuous. *At the end of 28 hours,* I discovered the heart itself at the side of the spine, presenting the appearance and form of a varicose and semicircular tubule, but it as yet exhibited no sensible motion. *After 34 hours,* I saw the præcordia still more clearly, consisting not only of the foregoing semilunar vessel, but also of certain fibres, which began to be loosely collected around it” (n. 245). And Malpighi says, speaking of the heart of the silk-worm: “This heart consists of thin membranes, which are of the same color as the fluid they enclose, being at first transparent, but afterwards becoming yellow, and losing some portion of their clearness” (n. 244). And again he says of the chick: “I think . . . that these vesicles pulsating in succession, constitute a true heart, surrounded as they are (for I have more than once indistinctly seen it) with muscular fleshy portions that have not yet taken on opacity or redness. . . . It is very difficult to determine by actual observation, whether the existence of the blood precedes that of the before-mentioned heart, or *vice versâ*. . . . At that time, all the parts are so mucous, white, and pellucid, that use what glasses we may we cannot see clearly into their structure. . . . Both the ventricles were succesively enswathed by spiral muscular fibres” (n. 242). Harvey has these words: “In a human foetus, about the beginning of the third month, I have seen the heart similarly formed, but white and bloodless” (n. 246).

275. The formative force therefore issues forth from the spine of its little medulla as from the first and golden age of its existence, whence it passes into another theatre of action, and there renews the disport of its determinations with the view of extending them over a still wider range; for which reason it first transcribes its power into the heart, which is designed to serve as the regulator of the future body, and which lies moreover close to the spinal sheath on the outside of the thorax, clothed by the medulla with fibres emulating the muscular, and adapted to the exercise of their proper forces in proportion as the blood receives its fixation in its ultimate



degree.\* Thus the spirituous fluid is the first cause, the purer blood is the second, and the red blood is the third (n. 271, 272). But the distinct periods in which the purer blood and the red blood respectively come into existence, are not so easily distinguishable, since one member derives consistence and acquires strength sooner than another; as the heart, for instance, sooner than the lungs; the liver sooner than the other parts of the body; and so on: although each of these emerges out of the fluid in its own proper order. The second age seems to commence when the heart first begins to appear, and the blood is circulated in a simple orbit, of which subject I shall speak in the next chapter.

276. The third age does not begin till the heart puts off its simplicity, and rolls itself up to suit the coming lungs, at which period the heart is still further compounded. “The præcordia,” says Lancisi, “which previously to the fourth day hang almost naked on the outside of the thorax, are on the fourth or fifth day covered over by a fine tunic, and gradually after the seventh day are concealed within the thorax” (n. 246). Again he says: “*On the 5th day of incubation*, one may without difficulty see that the right ventricle of the heart has approached to the left, and is lying upon it;” but the heart, as he observes, “is not of a conical figure until after the seventh day” (*Ibid.*) The reader should here consult the works of Malpighi, in whose figures he will have an opportunity of admiring nature’s play; after his feelings of astonishment have been excited by a perusal of these illustrations, he will be refreshed with the pleasing nature of the circumstances which take place at this stage of existence. This third age is more particularly that of the purer blood, as the second was that of the spirituous fluid. In regard to time, it is longer than the others; in regard to space, the operations are more widely extended; in regard to heat, there is a fuller supply; in regard to appearance, the parts are more prominent, as may be seen by help of a lens; in regard to touch, they are still very soft and tender; this age being one in which a corresponding treatment is required. The corculum or little heart is now seen to be traversed by the purer or white

\* Ut se figit sanguis.

blood. "It seems clear," says Malpighi, "that the ichor, or matter above alluded to, which afterwards becomes red, exists antecedently to the motion of the heart; but that the heart, as well as its motion, are antecedent to the rubefaction of the blood" (n. 242). "*After 38 hours, . . .*" says he, "a pulse was observable, and when this pulse ceased, a kind of dark line was at last traced." (*Ibid.*)

277. *The third, when by the medium of the red blood the lungs are brought into existence.* "*After 40 hours, . . .*" says Malpighi, "the heart pulsated, receiving from the veins a rust-colored humor, and sometimes a humor of the color of sere vine-leaves. . . . The aorta sent upwards certain considerable branches to the head, and was continued downwards in the form of a trunk, which after dividing extended as far as the extremity of the carina. . . . *After the 8th day, . . .* the heart pulsated in the usual manner, and lungs of a white color were seen to have sprung up beside it" (n. 242). Thus the pulmonary follicles are not visibly produced or excluded from the sinuses of the heart till the 8th day, nor can they be excluded before the ventricles of the heart have coalesced, and before the pulmonary artery is sent out from the right ventricle, and the pulmonary vein is continued into the left. Thus the first age of the lungs is the second age of the heart, or the third age of the brain and its spinal marrow. Whence it is evident that there is not a single member of the body but passes through its own distinct stages of existence. We are here however treating only of those general ages pertaining to the body, which are severally passed through, from the time of the existence of the first living point, according to the order of the fluids.

How or by what cause this most simple type of the heart, or this threefold vesicle, causes its separate parts successively to combine into one,—for instance, how the right ventricle of the heart twists back upon the left, fixes roots, superinduces muscular crusts, and knots the heart up into a cone; how the right auricle, which is afterwards fimbriated, and likewise the left, which arises out of no visible trace, extend over their respective ventricles, and both become united by an intermediate septum; how the foramen ovale is opened from the right into the left auricle, while the right ventricle, which hitherto had given no



sign of opening into any place, now forms a communication with the pulmonary artery, and from that artery sends the little arterial duct into the aorta; and finally, how the lungs, which are extended into the trachea, preclude the influent air from any access to the heart; are all questions the explanation of which I design to waive. Nor shall I say whether in so doing it be because these are subjects more of curiosity than utility; or because in explaining arcana of this nature I should not appear to the reader sufficiently clear or well supplied with facts, without first imparting to him an experimental knowledge of the organization and functions of the several members, and of the variety of the before-mentioned circulations of the blood, (for which see Chapter IV.;) or because of my ignorance, which I am by no means ready to disown, and which by saying nothing may possibly be studious to conceal itself. But meanwhile, whichever of these may be the reasons, I repeat, that so long as the facts themselves remain clearly ascertained, it may be better to waive their investigation rather than to use empty and obscure terms, which must exhibit only an unmeaning subtlety.

278. *The fourth, when the lungs themselves begin to breathe the air, which happens after exclusion from the natal egg, or from the genital womb.* This is the fourth age or general change of state, or the period of birth. For in the first age the cerebrum and cerebellum, acting as the successors of the parents, or as the new parents of the conceived offspring, look round for their first general\* aid in perfecting the stamen, and continually behold themselves as it were in their own body, from which they have emigrated with their thread and distaff (n. 273); consequently they behold the things which are subordinated as already present in the things which are to be subordinated (n. 261). When therefore the formative force is occupied in looking out for the most general kind of aid, it directs its attention first to the spinal marrow, from which the fibres of the nerves are brought off with their spirituous fluid; next these provide for the ensuing organs,—for the heart and the lungs; which latter, attracting by inspiration volatile particles from the air, are to

\* General, because the particular parts are not yet formed. Only the general outline at first is sketched, and hence only such materials for the completion of the body are required as are of this general nature.—(Tr.)

cause the blood to exist in the body as long as the body itself subsists. Hence there are as many general changes as there are degrees of substances and forces. Here we must pause, as we have now arrived beyond the primeval state of formation. Therefore,

279. *There are three general sources of motion, on which all the particular sources depend; for what is general is requisite in order that there may be a distinct particular: the general in the present case is, the brains, the heart, and the lungs. The motion of the brains is called animation (see Parts II. and III.), and the action of the spirituous fluid depends upon it. The motion of the heart comprises systole and diastole, and on these the circulation of the blood depends. The motion of the lungs is called respiration; on this the circulation of the purer blood principally depends. But since the purer blood is intermediate between the spirituous fluid and the red blood, therefore its circulation depends upon the motions of the brains as well as of the lungs. On this subject the reader will find numerous remarks in the sequel. The motion of the lungs will be discussed in Part VII., on the Tongue, Trachea, and Lungs.\* In the meantime, with respect to the circulation of the purer blood, see n. 359, seqq.*

280. *During the formation of the chick or the embryo, and previous to exclusion from the egg or the womb, the animation of the brains is coincident with the systole and diastole of the heart; but after the lungs are formed, and the chick or embryo is born, the animation of the brains dissociates itself from the motion of the heart, and conjoins itself with the respiration of the lungs. On this subject I must detain the reader for some little time, for unless these particulars are confirmed by actual facts, we cannot move a single step toward the theorems which are to follow in the present Part. The truth of this article hinges on the following propositions. 1. That there is an animatory motion of the cerebrum, and with the cerebrum, of the cerebellum and spinal marrow, which motion has been called by some authors a systaltic motion. 2. That during the period of formation, this systaltic motion exactly coincides with the systolic motion of the heart. 3. That after the period of formation, or*

\* The author altered his plan from time to time. Part VII. here mentioned comprises subjects fully treated of in the *Animal Kingdom*, Parts I. and II.—(Tr.)



after birth, it conjoins itself with the respiration of the lungs. 4. But that it again conjoins itself with the motion of the heart whenever it returns into a state similar to that of formation, or whenever the lungs cease to respire while the heart continues to beat, as in cases of drowning, suffocation, obstruction of the gullet, trachea and bronchia, in fainting, and so forth.

281. I. That there is an animatory motion of the cerebrum, and with the cerebrum, of the cerebellum and spinal marrow, which motion has been called by some authors a systaltic motion. So far as I may form a conjecture from the writings of the learned, there are some who do not deny motion to any viscus in the body excepting the brains and their medullæ. Thus the stomach and intestines have a peristaltic and vermicular motion; the lungs, an alternately expanding and subsiding motion; the heart, arteries and veins, a pulsatory and circulatory motion; the neighboring members in the thorax and abdomen, a motion in common with those just mentioned; and all other members a muscular motion: while the brains are allowed scarcely any motion but that of the arteries as they slightly raise themselves above the level of the surface. Now a machine like the brain, which takes such a leading part in all the efforts, forces and actions of the body; which is unwearied in its operations; which never ceases from the duties and cares resulting from its having charge of the body adjoined to it, must needs be always in the exercise of the highest activity, and experience alternate motions, in order that it may perpetually incite all those other parts of the body to action which are subordinated to it, and may vivify the fluid transmitted through the fibres. The truth of this circumstance we are shewn by experience, and we are taught it likewise by the relation of causes. Nor is there any right to expect that we can ever arrive at a true knowledge of the cerebrum and cerebellum, the nerves, muscles, and viscera of the body, without first admitting the fact of the animation and alternate expansion and contraction of the former. Indeed, there is not in the brains and their various processes a single furrow, ridge, cavity, fibre, artery, or vein, that does not indicate and most distinctly prove, that both the brains and their medullæ are formed in motion and for motion. Let us then once set the machine in motion, and the use, effect

and end of all its members will be evident to the senses. In cases in which the head has been wounded and laid open, the dura mater, and more especially the subjacent brains, are seen to be in motion. Ridley laid bare the dura mater, and after opening the longitudinal sinus, and allowing some of its blood to escape, detected a motion exactly synchronous with the pulse of the heart. (*Anatomy of the Brain*, chap. vi.) Pacchioni declares that the motion of the dura mater is not simply pulsatile; although, according to Mayow, when the cranium is perforated so that a portion of the brain comes into view, the brain itself is seen to swell, and then to subside. (*Opera*, p. 152, 153; 4to. Rome, 1741.) Where the coronal spine and the crista galli of the ethmoid bone decline into the plane of the cranium, they are succeeded by the front portions of the frontal bone, which on the concave side, facing the lobes of the cerebrum, are formed into such hollows, that the gibbous projections of the anterior lobes of the cerebrum can advance into them and there make their abode. In these hollows, and round about them, the arteries of the dura mater are seen impressed and effigied upon the bone. The same is the case in the large parietal bones, where beside the little canals which are carved out for the longitudinal and the two lateral sinuses, there are arborescent grooves of smaller canals answering to the arteries of the dura mater, which are in some places deeply imprinted upon the cranium, and sometimes adhere to it. We may likewise clearly see sinuous furrows on the temporal bones, (though less clearly near their sutures,) exactly fitting the serpentine convexities of the cerebrum; as shewn in the Tables of Bidloo, Cowper, and others; and in the description given by Vieussens, who says: "Such traces of the exterior figure of the convolutions of the brain, could never be imprinted upon the inner surface of the skull, if the brain were entirely destitute of motion; for no one, we presume, will affirm, that the dura mater, as it lies between the skull and the brain, is capable of producing depressions in the skull." (*Neurographia Universalis*, cap. vi., p. 41; fol., Lyons, 1685.) Moreover, in the brain there are perpetual convolutions which allow themselves to be expanded, elevated and compressed, in a manner exactly corresponding with the direction of the furrows interposed between



them. There is likewise a space between the membrane proper or proximate to the brain and the dura mater; in order that the brain, if capable of elevation, may be elevated. There are also fibres like muscular fibres at the sides of the sinuses, and in the sinuses themselves there are chords that exhibit a manifest motion originating from the brain. There is also in places a fibrous substance between the corpus callosum and the falx, of which Willis makes mention. (*Cerebri Anatome*, cap. vi.). The fluxion of the tendinous fibres, of which the falx, the transverse septum between the cerebrum and cerebellum, and the dura mater from the falx to the peripheries, are constructed and framed, points out not only that there is a motion, but also what that motion is. The very sinuses themselves, and all the arteries and veins of the brain, are disposed according to the stream of that motion. There are ventricles and hollows, which afford the brain room when contracting, and close when it is opening, and which enable the effect of the action to become determined toward either the interiors or exteriors. There are also chinks, such as is that of the third ventricle, which would be perpetually closed unless the cerebrum opened the fissure into the space beneath. There is therefore some internal action in the brains, which, according to the experience of Ridley, may even be perceived by means of the fingers. (*Anatomy of the Brain*, chap. vi.). In a word, throughout the entire fabric of the brain, there is nothing which presents itself to observation but tends to confirm the fact, that there is in it a general animatory motion. Without motion the blood could not be expelled from the larger trunks of its arteries into the smaller, much less could the bland juice be expressed in so large a quantity into the ultimate capillaments of the cortical substance and of the fibrils. Moreover the arteries and veins in the brains, having no muscular tunic, can be acted upon only by some common force, intumescence, and depression, proper to the mass of the brain itself; not arising from the heart, because without auxiliary fibres or motory rings round its arteries and veins, this organ could not extend the force and sphere of its action into the very penetralia of the brain itself. For what I have already said on the muscular coat, see n. 217. The blood moreover in its passage toward the interiors of the brains through their me-

dullary substance, would lodge in its several diverticula, where it would appear sprinkled about like stars in their hemispheres, incapable of making the slightest progress, unless at stated intervals it were pressed onwards by the brains. Without a general motion of the whole brain, not only the juice that flows in its fibres, and that also which flows between them, would be incapable of being expelled, but so likewise would that which lies between the membranes, and which is often collected in large quantities within the ventricles. Within the space of an hour the pituitary fluid would also be in a state of congestion, from being unable to travel along the several passages which animal nature has so providently and ingeniously constructed for it. The brain therefore is formed in motion and for motion, and as I have above observed, let us only set the machine in motion, and the use, end, and effect, of its several parts will at once be made manifest to the senses.

A motion similar so that we have here called the animatory, is observable in the rudimentary brain. "I have often remarked," says Malpighi, "as a usual piece of nature's play, a motion present in the zones, by the coming and going of which, the areas and cavities of the carina were either enlarged or obliterated" (n. 243). But the proximate cause of the animation of the brains is a matter of dispute among the learned. In Parts II. and III., I shall shew that it arises from the animation of the cortical and cineritious substance of the spherules, and thus primarily from the soul itself governing the motions of its own fluid. The reader may here consult n. 177, where it was pointed out that the animatory motion of the brain depends on the cortical spherules, and hence as it were upon an infinite number of little hearts, one of which is prefixed to each of the fibres.

282. II. That during the period of formation, this systaltic motion exactly coincides with the systolic motion of the heart. Of this we may have ocular demonstration by merely inspecting Malpighi's figures in his little treatise, *De Formatione Pulli in Ovo*. We are there shewn, that from the last vesicle of the heart, the blood sends out three principal branches running to the head only, which meet together and form a larger canal; that this canal reaches round the extremity of the carina,



and finally separates into the umbilical branches. So that this simple little heart directs its sanguineous stream first of all to the brain, and there collects it as into a little reservoir, in order that it may be driven round by virtue of the motion of the brain and of the zone before mentioned. It is shewn also that the heart has its origin by the side of the spinal marrow, in order that it may be kept under the influence of the motion thereof, which is one and the same with that of the brain. Hence it is, as Lancisi says, "that as soon as the motion of the corculum begins, certain fine purpurascient lines (which prove to be the umbilical vessels) are traced from the border, or from the circumference of the colliquamentum in this situation, (as we said above,) to the centre of the cicatricula, where they terminate, and becoming enlarged form those vesicles, which are alternately filled, elevated and reddened by the influent blood; in other words, undergo diastole; and on the other hand, when the blood is propelled by them, are depressed and contracted, or perform a systole, during which action they become invisible, and vanish away" (n. 245).

Reason itself as based upon these facts leads us also to the same conclusion; for in this new empire of the foetal body perfect unanimity ought to reign everywhere; I mean, between the brain and the heart. For the heart is provided to the end that in the minutest recesses of the body where there are fibres there may also be vessels, where there is spirituous blood there may also be red blood, each provided in its own order and one consentaneously with the other: or to the end that where the heart is present the brains may be present; an effect which could in no wise be obtained without a perfect agreement between the motion of each. This we find exemplified in the glands, muscles, and all the visceral textures, in which, where a vessel from the heart acts, a fibre from the brain also is present and acting, both conspiring to the production of the same effect. Thus all the vessels of the body in conjunction with the brains, like the only two classes of citizens now in existence, give rise to all the various other members of the community. Thus also we see the connection between the parts of the animal body; for ultimates ought always to consociate themselves with primaries, in order that intermediates, which can only in this

manner be rightly linked together, may not be conscious of the regimen under which they are placed, and much less be anxious to rid themselves of it. When the functions of life are carried on in this involuntary manner, we do not find the action of any muscle exhibited to view, or coming into the distinct perception of the brain, as is the case in adults; neither is any fibre as yet capable of acting against the blood, or the blood against any fibre, as is afterwards the case when the fibre contracts and the blood dilates it. This occurs only after birth, when the fourth stage of formation has commenced; that is to say, provided the heart and brain have each been endowed with their own proper mode of acting. This you will see confirmed by many arguments in the succeeding Chapter, where we purpose expressly to treat of the primeval circulation of the red blood, and more particularly in Part II., on the Motion of the Brain.

283. III. That after the period of formation, or after birth, it conjoins itself with the respiration of the lungs. The last general change of state cannot take place, before the brains, heart, and lungs are completed; or according to the account given by Malpighi, before the cristate vesicle is divided, the intermediate vesicle depressed, the vesicle at the top [*supereminens*] furnished with a rivulet of red blood, the brain partitioned into hemispheres by the falx, a sinus interposed, the ventricles opened, the infundibulum formed, as well as all the organs and vessels, &c., of that most noble chemical laboratory; &c.: that is to say, until the brains are able without danger, to dissociate themselves from the motion of the heart. But let us proceed to facts. 1. From the anatomy of the brain it is clear, that its blood vessels are regulated in a different manner from those of the body (n. 217, 218, 219),—that the former are not under the same laws as the latter. It may also be shown, that the former do not obey the influences of the principal heart, which is that of the body, but those of an infinite multitude of little hearts (n. 177) pertaining to the brain, which is in the principles of all the forces and actions of the body. From the nature of the connection subsisting between the organs, it may also be seen, that the pulsations of the arteries of the brain may or may not coincide with those of the heart, for their spheres of activity are separate, and boundaries are placed between them



(n. 217). This may be seen much more easily than in the case of the motions of the lungs and the heart, which are still more united, inasmuch as the right ventricle of the heart is continued immediately into the arteries of the lungs, and the pulmonary veins are continued into the left ventricle of the heart. It is therefore possible that the motions of the brain and heart may or may not be synchronous. 2. But whether the animations of the brain, under which term I comprehend the cerebellum, the medulla oblongata, and the medulla spinalis, coincide exactly with the respirations of the lungs, is a question which remains to be solved. It is well known that the brain can feel and will, can determine its will into acts, and thus exercise power over the muscles of the body. If now it should be demonstrated by actual fact that such a determination to act is made by means of particular elevations and constrictions of the congeries of the cortical substance, which in the part on that subject we shall call cortical tori or thalami, it will follow that it is in the power and will of the brain to expand and constrict the whole of its substance, so that its animation shall be altogether subject to its will in the same manner as is the respiration of the lungs. The case however is not the same with the pulsation of the heart. 3. To pass over innumerable facts, and arguments founded upon facts, it is plain from the anatomy of the brain, that the air which is received through the nostrils excites the brain to contraction at the moment in which it is passing through the trachea to the lungs;\* for the olfactory nerves subtend a considerable portion of the base of the brain, and diffuse their radicles through a large portion of its medullary substance; so that when the nerves are excited, the brain necessarily acts in concert, for the air every where in its course along the large pituitary membrane, meets the glands, papillæ, sentient meninges, and fibrils which are extended thither from the mammillary processes. Let not the reader be surprised at my affirming that the brain is constricted by an externally exciting force, since the brain itself appears to be in the cause of animation. There are many facts to shew, that the brain is expanded by the force of its own animation, but is driven to contract by various

\* See the *Animal Kingdom*, Part II., Chapter I., on the Nose.—(Tr.)

other causes, such as the dura mater, the falx, the horizontal septum, the arteries, the veins, the sinuses which are then extended and compressed, and likewise the nerves which are stimulated by any of these causes. For an infinite number of means conspire to the production of one effect, which means are provided to the end that the effect may never fail of being produced. The motion proper to the brain is animatory expansion; constriction being a species of exanimation, which is opposed to expansion, as it is hence also to life. The case is the same as with the lungs, which live by expansion, as the blood then travels through the arteries, but which expire and die by constriction. We may form some idea of the size of the pituitary membrane, which is continuous with the meninx of the brain, from the fact that it constitutes the membrane of the six sinuses; namely, the frontal, sphænodal, and maxillary, and of the cells of the spongy and turbinated bones; whence a contact between the air and this membrane can never be wanting, nor consequently the effect of this contact; namely, a constriction of the brain, which constriction must thus arise from a multiplicity of causes. The truth of this assertion may be still more plainly seen from a consideration of the external causes of sneezing, an affection during which the thorax and abdomen, together with the lungs, are expanded by a species of convulsion, and the brain consequently becomes constricted. Willis supposes it to be unquestionable, that when persons sneeze the dura mater is strongly contracted (*Cerebri Anatome*, cap. vi.); he would possibly have said the brain instead of the dura mater, had he not previously denied any motion to the brain. This indeed is seen to be the case in persons who have been struck on the head, and had the brain laid open. Besides, sneezing is only the lowest degree of constriction; all other constrictions are of an intermediate or secondary degree, arising from a similar but slighter cause; both kinds however proceed from the irritation of the same pituitary membrane, so that either the constriction or irritation being granted, the other follows. Infants, as soon as they are born, change the order of internal motion, and for the most part, on first meeting the air, salute it with a sneeze. The effect produced by the brain when contracting, is generally sensible to us; for it is by means of sneezing that



the brain expels the pituita that clogs the entrances, on the expulsion of which the brain composes itself, and reduces the cortical tori to their proper order, which it could not do without a deep contraction and sudden expansion. The character of the natural expansion of the fibrils or origins of the mammillary processes, is evident in brutes; for when the mammillary processes are inflated, the whole brain swells up, because these fibrils are disseminated throughout all its lobes. But in man the case is different, because the mammillæ are smaller, and their originant fibres not so widely diffused. This is ordained, to the end that external stimuli may not, as in brutes, be always inciting them to a lively motion, and in order that man may be at liberty to pursue his thoughts.\* It is well known, that a person whose mind is intent on any subject, wrinkles his forehead, contracts his eyebrows, places his finger between his eyes, converges their axes into an acuter angle, closes the eyes against external light, shews from under the lashes a glimpse of what is passing within, contracts his cheeks, lips and breast, breathes slowly and tacitly, elevates the lungs higher as it were, reciprocates them when but little elevated, lest by too great a collapse they should afterwards fetch too deep a breath; and respire through the mouth, and not always through the nostrils, a habit which is peculiar to man. While the mind therefore is intently pondering on the different relations of things, the brain in general with the lungs is comparatively quiescent, in order that its leisure may be undisturbed; hence it avoids drawing breath through the nostrils, or exciting the olfactory nerves, on which account these nerves are smaller in man than they are in brutes. It is unnecessary to notice, in addition to what is here stated, the phenomena of gaping, which are themselves also modes of elevating the sleepy and indolent brain. I need also say nothing of laughter, of stretching the limbs, and other natural media coinciding with the lungs, and by a kind of instinct suggesting themselves to us with a view to excite the brain.

4. It has been above observed (n. 217), that the arteries of the heart have no power over the arteries of the brain, on the principle that that which is subservient has no power over that which

\* See the *Animal Kingdom*, Part II., Chap. I., n. 343 (a); n. 349 (y).—(Tr.)

commands. The arteries of the heart have also no power over the arteries and veins of the spinal marrow, which observe a motion and time similar to those of the brains. For the spinal marrow expels its blood through the same foramina, through which it gives out the nerves; from these foramina it sends the blood into the azygos, a vein in which almost every vein meets that comes from the respiratory field. The azygos connects itself with the bronchia and trachea by fibres and vessels, and this, in such a way, that it cannot possibly be opened unless the bronchia give way, which they do at every expiration; at which period only can the valve, or muscular semisphincter between the azygos and superior vena cava, be expanded. There is therefore a continuous connection of causes extending from the lungs to the medulla spinalis, and from the medulla spinalis to the medulla oblongata, the cerebellum and the cerebrum; in which chain of connection, according as one link is moved, so is the other. The sphere of the heart's activity cannot be extended into the vertebræ through the arteries; for the anterior spinal artery takes its rise from the vertebral artery after it has entered the cranium, and above the medulla oblongata, from which it issues downwards; while the posterior spinal artery takes its rise from the vertebral artery without the cranium, namely, from the aorta and lumbar artery; although at the same time it in part arises from the vertebral artery within the cranium, near the fourth ventricle. But the branches traverse the same notches through which the spinal nerves pass, where they are necessarily reduced by mutual contiguity into the determination of another motion. This is effected by a most wonderful contrivance, in the following manner: the notch of the inferior vertebra is made to fit into the notch of the superior, (on which subject I shall speak elsewhere;) and the moment they enter this notch they send out small twigs into the little hordiform ganglions, into the first beginnings of the nerves, and into the surface of the medulla spinalis, which are all in the same stream of motion as the medulla spinalis; so that the sphere of the activity or vibrations of the heart extends itself only to the vertebræ, and not beyond. 5. In confirmation of this synchronism and concordance of the cerebral and pulmonary motions, we might derive arguments from numerous other parts, both of the brain



and of the body; as from the intercostal nerve, which in the body is the substitute for the cerebellum, and surrounds all the branches of the azygos: from the par vagum, which in like manner is an offset of the cerebellum, and does its general behests in the body. The clearest possible arguments may be drawn from the costal nerves, which move the muscles connected with respiration at the same moments that the medulla spinalis constricts itself. For in our Part on the Motion of the Brain, it will be shewn that when the medulla spinalis, by its expansion and constriction, acts upon the origins of its nerves, and thence upon their ganglia which are exterior to the vertebræ; when again these ganglia act upon all the nerves, and these nerves upon the muscles of the body, then the muscles which have no antagonists, such as the intercostals, and the muscles which are acted upon immediately or mediately by the twelve costal nerves, either open or shut the cavity of the thorax according to the room afforded, by which means sufficient space is created for the lungs to allow of inspiration, or else is taken away for the purpose of expiration: an action which coincides exactly with the spontaneous animation of the brains, or the voluntary animation of the cerebrum. Arguments may likewise be deduced from the ninth pair of the nerves of the head, as also from the second pair; the former of which principally serves the tongue for the purposes of speech, which it could not do if the animations of the lungs and the brains did not coincide. Inasmuch however as arguments deduced from these organs presuppose a connection first demonstrated, and consequently a continuation of effects from first causes through intermediates, I cannot at present dilate farther on this part of the subject, and I reserve it therefore for Part II., on the Motion of the Brain. 6. The anatomy of the silk-worm, as given by Malpighi, obviously leads to the same conclusion; for the cineritious substance of its brain and spinal marrow, contained within prolongations of the medullary substance, and divided into globules, acts principally upon the tracheal pipes of the lungs; for the medullary substance surrounding it at every nodule gives off two nerves expressly to the tracheal pipes; and this substance does the like where it is contained within the cranium, whither the topmost tracheal ramification also enters. (We must bear in

mind that the silk-worm has many tracheas or lungs,\* as well as many hearts). Moreover, the very blood-vessels, which run over the whole extent of the spinal marrow with its distinct globules, expand exactly upon the tracheal pipes of the same lungs. (*De Bomb.*, p. 16, 20, 21.) Hence the action of the brains, that is to say, of the globules of the cineritious substance, being granted, an immediate effect flows into the proximate tracheal pipes or lungs. This being manifest upon a very slight examination of Malpighi's figures,† mere conjecture is at an end. Since then there are three general fountains of motion (n. 279), and the motions of the brains are the first, and those of the lungs are the last, hence by the consociation of the first and last motions, the intermediate motion of the heart, and all the other subordinate motions, are constantly kept in their even tenor and order. The facts and arguments here adduced are indeed few, but the reader will hereafter find our position established by a multitude of data. In the meantime I may observe, that there is nothing but tends to confirm this view of the subject; as is always the case, where what is advanced is the truth (n. 10).

284. The only phenomenon that might at first seem to militate against the fact of the concordance of the motions of the lungs and brains, is, that when we lay our fingers upon the fontanelle in infants, we feel that the longitudinal sinus of the dura mater exhibits a movement synchronous with the pulse of the heart. But if we look into this matter more closely, it will be found, that it is not the sinus that pulsates, but the luxuriant arteries of the pericranium and dura mater, which traverse this part at this period of existence. It is clearly shewn in one of Ruysch's Figures, (*Thes. Anat.* v., tab. ii., fig. 4,) that two little arteries run lengthwise under the fontanelle, and numerous arteries breadthwise; and since they do so in company with the other arteries of the dura mater, that is, of the lamella thereof that covers the sinus above, and of the other lamellæ that form the sinus laterally, hence a pulsation is produced apparently as of the sinus itself, and hence of the cerebrum; an appearance by which I confess that I myself had often been deceived. For

\* See the description of these by Malpighi, above, n. 123.—(*Tr.*)

† See Malpighi, *De Bomb.*, tab. iii., fig. 1, 4; tab. vi., fig. 1, 2.—(*Tr.*)



the sinus itself, being the largest vein of the head, cannot pulsate for the reasons mentioned above (n. 190—197), as neither can any vein in the body; for a pulse is an elevation of a vessel that takes place only when a wave is travelling successively from one place to another. But in the longitudinal sinus there can be no wave travelling in this manner, because it receives venous offsets from every point of its channel, as will be seen from the anatomy of this sinus in Part II. With respect to the fact above related by Ridley (n. 281), who discovered, as he says, that the systaltic motion of the brains exactly corresponded with the vibrations of the heart, I do not deny that such a motion might exist in a dog, so fastened with a ligature as to have its trachea or throat constricted, and the motion of its lungs entirely intercepted, as we shall presently have occasion to observe.

285. IV. But that it again conjoins itself with the motion of the heart whenever it returns into a state similar to that of formation, or whenever the lungs cease to respire while the heart continues to beat, as in cases of drowning, suffocation, obstruction of the gullet, trachea and bronchia, in fainting, and so forth: or in the words of our proposition, *the animation of the brains again conjoins itself with the motion of the heart, whenever, from various causes, the lungs cease to respire, while the heart continues to beat*. For from that moment the voluntary action of the brain upon its muscles ceases; the sensation of the organs is likewise deprived of its life and lost in obscurity. An appearance of night supervenes, and there is a return as it were to that state of the body and brain which existed during their primitive formation,—a state of oblivion, inaction and insensibility. For then the brain does not summon its own blood, or dispense it according to necessity and requirement, but only admits the blood which comes to it from the heart, and hence lives as it were under the control of the body; for which reason it can exercise none of those functions that belong to it as a lord and master. But this subject will be better understood further on.

286. From the foregoing remarks it appears, that there are three general fountains of motion, namely, the brains, the heart, and the lungs; and that the brains and lungs are a more general cause than the heart itself, because the brains act upon the

nervous and muscular fibres, or upon the spirituous fluid, and the lungs together with the brains give force to the muscles, and at the same time incite the vessels of the purer blood to motion, and consequently promote the universal circulation (n. 154); while the heart promotes merely the subordinate circulation, or that of the red blood.

287. But we have further to consider that the motion of the brain should be conceived of as taking place according to the partition of its substances, or, as general, special, particular, and hence variously subdivided. Thus the brain is divided into hemispheres, the hemispheres into lobes, the lobes into serpentine ridges, the ridges into tori, the tori into clusters [*racemos*], the clusters into spherules, and the spherules into lesser and least spherules. For this reason the brain possesses the faculty of expansion in general, in special and in particular; for the whole brain may be unfolded, or a single lobe, or only a portion of the cortical substance. Hence, if in consequence of any serious obstruction, one half or one hemisphere should become torpid, the brain could nevertheless unfold its other hemisphere; if a single lobe should become so, still the other might experience an alternate motion; if this lobe should lose its action, then one or the other of the serpentine tumuli might be brought into play; should the whole cerebrum become quiescent, then the cerebellum and each medulla might be made to act, especially in the human subject. In the sciences of physics and cosmology it is well known, that a mass or volume of one and the same body may experience a general, a less general, a particular, and an individual motion, simultaneously, and yet that one motion shall not interfere with the other. It is known that the general motion in relation to the subdivided or particular motion, in which and under which also the more particular motion subsists, is or appears to be as none, and has the semblance of a state of rest; as in the case of undulations within undulations, modifications of auras within modifications. This indeed is the actual state both of the universe itself and of all its living machines. The whole heaven may be perpetually\* revolving in a vortex. The planets of this heaven may revolve

\* Rotari et volvi.



in their orbits, and at the same time turn upon their axes. On a planet, thus the subject of a twofold or threefold motion, the ocean may be rolling. On the ocean ships may be speeding their course. In a ship the sailor may be walking the deck, or climbing the yards; in him the arms, the loins, and the chest may be all in motion: in these parts the lungs, heart, and brain may be pursuing their several alternations; in the lungs, heart, and brain the blood may be circulating; in the blood, the parts may be undergoing tremulation; in these parts the purer substances may be undergoing modification; and in these again the purest likewise. And all these motions may be taking place at one and the same time; and the particular shall be unconscious of its more general and universal motion, and the more general and universal, of the more particular motion. Such also in miniature is the animal microcosm, and more especially, the principal wheel of the machine, or the brain.

288. *Moreover, the primitive fabric of the heart, and the character of the pulse, in those animals that have one heart, and also in those that have many hearts, all conspire to shew, that the primitive corculum with its three distinct vesicles, in the nature and mode of its action resembles both the veins and the arteries, between which these vesicles are intermediate.* Let it be granted that the venous blood has a determination equally in every direction both upwards and downwards (n. 190—197): hence that it has a determination towards the heart or its auricle. Let it be granted that the arterial blood has only one determination, that is, to the extremities of the branches (n. 182—189); so that a wave which has once passed from the left ventricle of the heart is carried on in a given undulatory current (n. 166—172). It will then follow that there are two sets of vessels, arterial and venous, meeting together, and having a twofold nature and mode of action. Now these two sets cannot possibly be conso- ciated without the interposition of vesicles; for were there no vesicles, either the blood would be carried on in one continuous current without any pulse and undulation, or if the simple pressure of the vein could not perpetually keep open the little entrance into the arteries, the current would stop, and all circulation be intercepted. The vesicles are therefore as it were em- bankments, stations, and landmarks, for converting the mode

of acting belonging to one kind of blood or vessel into that belonging to the other.

289. Since then the veins are merely the receptacles of their blood, since they push it equally in every direction, and since it perpetually presses on the little heart that determines the stream by its alternate action ; it follows, by the connection of causes, that in the primitive state and before the heart is of a conical form, the existence of three oval vesicles is required ; for, as we have said, these vesicles are as it were stations where the veins meet to deposit their burdens, and to repose, and whence the ever-vigorous arteries run forth to create ampler spaces turgid with blood. For the first of the vesicles, which afterwards changes into the right auricle, is merely recipient of the blood now pressing upon it ; the second, which afterwards becomes the right ventricle, determines the blood as yet uncertainly, although slightly, toward the succeeding vesicle ; the third, which afterwards becomes the left ventricle, concludes the process of determination, by directing the blood into the arteries : a result which could not be attained without this primeval state of simplicity together with a state of triplicity. This is the way, and no other, in which the mode of acting proper to one vessel passes into that of another, according to the proposition, that *an intermediary receptacle discriminated into three oval vesicles, is the result of vessels of dissimilar nature and mode meeting together.*

290. *Furthermore, the simple fabric of the primitive corculum reveals the state that is ultimately intended for the adult heart and arteries.* Every comparatively simple or less compound subject exhibits a likeness and image of the things that follow ; although not of such a nature that the type of the compound is discernible in the component, or the image of the largest in the least (n. 249). For it is in a kind of middle state, so that while it is formed for its consequents, it refers itself to its antecedents (n. 252) : and regards in itself that which is to be formed as already formed, and *vice versâ* (n. 261). Therefore this corculum designates all that is to be in the adult heart and arteries.

291. *Firstly ;* it designates the possibility of the coalescence of the heart into auricles and ventricles, or of the formation of



the first vesicle into the right auricle, the second vesicle into the right ventricle, and the third vesicle into the left ventricle. These changes do not appear to be designated by any enlarged spaces; nevertheless that they are designed, is clear from the effect produced. But the particular convolution of the fibres upon these vesicles, and the adaptation and designation of the parts thereby, has not yet been discovered even by the microscope. It is however known that this triple vesicle is capable of being successively contorted, and that one vesicle may be located on the upper part of the other, and may be connected and united with it, as is evident both from their form, and from the process so particularly shewn in Malpighi's figures. We may therefore affirm, that in this simple corculum, the compound, or the entire heart as it will be, is already present; consequently that the auricles, ventricles and other parts are already designated, each in the way proper to itself.

292. *Secondly*; this simple fabric of the corculum, involves the presence, and as it were inherent necessity, of the circumstance, that the heart should commence and carry on a systole and diastole by means of an alternate elevation and successive distension; for one vesicle moves and pulsates after the other. "On the third, fourth, fifth, and sixth days," says Lancisi, "not one, but two salient points or corcula are visible, one being the right auricle, which is the first to beat, the other consisting of the two ventricles, which rise and pulsate after the auricle. . . . The following circumstance likewise ought here I think to be mentioned; namely, that the motions of the auricles, which as I before said are observed to be alternate with those of the ventricles on the first days of incubation, appear to be successive rather than alternate after the heart has attained its conical form; for I saw the contraction of the whole corculum begin from the auricles indeed, and terminate in the ventricles, but I have not seen this action amount to a complete alternation" (n. 245). And Malpighi says: "*After the lapse of 2 days, . . . the heart, pendulous on the outside of the thorax, beat with a triple pulse; one part of it pulsating after another in succession. . . . At the end of the 7th day . . . there were two successive motions in the ventricles, and the same number in the auricles,*" &c. (n. 242). The difference between the

motions existing in the primitive heart, and those existing in the adult heart, appears to be, that in the primitive heart the pulse is triple, and is successive from the first vesicle to the third. In the adult the pulse is double, or is a motion of both auricles simultaneously, and of both ventricles simultaneously; although still, even in this case, the pulse is alternate and successive in such a manner, that what is successive in the two last vesicles, becomes afterwards simultaneous when they merge into the two ventricles. The reason is, that the two are at length connected and compounded. For nature is always similar to herself in this, that what is successive must precede what is simultaneous.

293. *Thirdly*; that the arteries following the heart are to carry on in successive order the same functions which the initial heart commences as their fountain-head, or are to continue their heart by means of the successive detrusion of the blood; but nevertheless in such a manner, that what is successive-alternate in the heart is successive-continuous in the arteries. Into these distinctive modes and laws of action the arteries are initiated from their very cradles; namely, into that sort of course and current which afterwards familiarized by its extreme simplicity, or in other words, is rendered natural. Hence arises the general equilibrium of pressure exercised by the arteries in the direction of their extremities, and the ready transmission of the wave in the same direction. Moreover, it is provided by an astonishing skill and contrivance, that before the arteries are habituated and inaugurated into this mode of acting, the sanguineous stream shall be determined from its triple source into the larger trunk; into that for instance which is reflected upon the head: for in the early period of existence the brain coöperates as a cause with the heart, and its animation is synchronous with the motion of the heart (n. 282). Hence before the initiation of the cardiac motion, the brain makes every effort to give to the blood a proper circulation. In this manner the arteries are inaugurated under the auspices of the brains into their proper modes of acting, and the brains are continually putting forth and winding off their fibres thither according as they are required; the vessels are therefore from the very first conceived and born into the custom of propelling the blood. For were this not the



case, why should the initial heart entrust its diminutive wave to a vessel so slender and weak as the artery ; or how of itself could the heart propel it through so many windings and mazes ? Assuredly without some perpetual aid derived from the arteries, the little volume would stagnate at its first outset, unable to make any advance ; for the artery is at first but a mere oozy matter or pituita, and if it offered any resistance, or suffered itself to be actuated only by the influence received from the heart, it would require in forwarding the blood an additional auxiliary vesicle at every step. This is more particularly the case in the corcula and arteries of insects, and especially of small fishes, which are so soft and yielding to the touch that they more resemble mucus than a vessel of any consistence. In order therefore that the arteries may be initiated into their proper modes of action, it is wonderfully ordained that in embryos they shall be habituated to sustain the force of the blood expelled from the heart, by means of the lobular substance of the thymus gland which immediately surrounds the great arteries. Malpighi has observed a similar arrangement in the silk-worm. “There is yet another body,” says he, “that besets the surface of the heart, and has offsets adhering to the latter on both sides. . . . There are, then, a kind of mucous ramifications that surround the cardiac tube, by which the muscles also are covered. . . . It [namely, this body or these ramifications] is soft and tender, and so divided into oblong pieces or shoots, and so singularly involved, that . . . it is impossible to discover its real structure. . . . In the larger caterpillars these white ramifications entirely cover the inside of the belly, and . . . ramify in the manner of vessels, and inosculate with the branches next them similarly ramified, the whole series thus constituting a loose network. . . . In some places they [are] very narrow comparatively ; in other parts they assume the form of leaves,” &c. (n. 244). Nevertheless, prolongations of this kind are at the same time serviceable for other purposes also ; for it is one of nature’s secrets in her most perfect state, to elicit several different effects from one and the same thing. But these subjects will be treated of when I come to speak of the thymus\* and bronchial glands, the

\* See the *Animal Kingdom*, Part II., Chapter VI.—(Tr.)

sinuses of the dura mater, and those other parts of the body which are prominent in infants, but which in subsequent age decrease in bulk and consistence, as in use.

294. *Fourthly*; the primitive corculum designates the future state of the adult heart in this particular, that it not only can receive from the veins a greater or less quantity of blood, but that it sends back the quantity received, and which it cannot propel into the arteries, and in this manner inchoates and adjusts both its own equilibrium and that of the arteries and pulses. Lancisi says: "In this successive and alternate distraction and contraction both of the right auricle and of the ventricles, . . . we sometimes, as a matter of curiosity, have observed that these motions are presently inverted, if the right or left ventricle be slightly pricked with a needle: and the same may be observed much more readily in the corcula of insects" (n. 245). Shewing that the three cardiac vesicles are in the exactest balance of equilibrium, and particularly the middle vesicle, which is neither arterial nor venous, but between the two, and doubtful whither to propel the blood until the last vesicle superadds its force, and the unresisting\* stream thus enters into the recipient arteries. The blood is thus readily conveyed in either direction, probably lest the heart and arteries should suffer detriment from any affection of the animal mind, which is a chief cause in varying the equilibrium of pressure exercised by the arteries. For in the silk-worm, butterfly, and other insects with many hearts, the spectacle of a complete olympic sport is presented by the blood, which runs forward and backward according as the animal mind is affected, or the body punctured and distressed. Thus "in the heart of the butterfly," according to Malpighi, "nature is by no means so constant in the . . . direction [from above downwards] but that it may be altered by even a slight cause; perhaps indeed nothing can be less constant: and in truth there are . . . many . . . anomalies in this motion of the hearts. . . . I . . . remarked in the butterfly a motion of the heart . . . from below upwards; and then . . . from above downwards. . . . In the chrysalis . . . the motions of the hearts were directed from the head to the lower part; then from the

\* Parum resistens.



latter to the middle ; from which the fluid was sent back . . . like a hand-ball, to the tail; and this game of nature lasted . . . for no inconsiderable time, until two motions, directed to the opposite ends, burst forth from the middle, upwards and downwards : and at last a single motion was left, namely, from above to below" (n. 244). For in proportion as any pain of the body or affection of the mind actuates or constrains, the little muscles are more or less strongly excited to exercise their forces, and hence the blood that is to nourish the different parts is propelled according to the affections of the body or mind. Now the arterial system would not be introduced into this mode of acting, unless the initial heart, during its state of simplicity, on the slightest supervening stimulus, were kept in an ambiguous state between flux and reflux,—in a state capable of going off into various action in whatever direction the brain as the stronger power may drive it. By this means the consequences of any unexpected motion or assault proceeding from the animal mind, are obviated ; for otherwise the work of formation would be completely marred.

That something of the same kind is designated and remains in the hearts of infants, will be shewn in the next Chapter ; and that this is also the case in the hearts of adults, will be seen in Chapter VI., when we come to speak of the Coronary Arteries and Veins.

295. *But these things take place with a difference according to the perfection or imperfection of the animals in which they occur : also according as the animals are formed in the womb, or are formed in the egg.* Thus there is a difference with regard to oviparous animals, which find in the thick albumen and yolk of the egg everything already provided in admirable readiness, and feed upon them in the order in which they are compounded, as the viscera demand to be perfected and renewed ; and do not abandon the nursery of the shell till all its supplies have been exhausted. The case is otherwise with viviparous animals, which eagerly seize from the so-called ovulum a most refined essence, which the mother pours into those diminutive goblets ; that is to say, through the peduncles or roots into the ovulum, after it has permitted itself to be rolled through the Fallopian tubes into the uterus in order to connect the placenta with the uterine

vessels ; by which means viviparous animals in the womb of the mother obtain their frugal supplies. These spirituous and sanguineous materials, after being first filtered in their passage through the placenta, are carried next through the umbilical vessels to the liver, where they undergo a second filtration, lest any unprolific or noxious substance should strike against the soft and tender brains, which require for their purposes none but the richest pabulum, and such as will produce and support the several members of the body in the order of their formation. For this reason viviparous animals, presently enclosed in their membranes, do not pass through states of a like duration with the oviparous. Neither is their heart pendulous on the outside of the thorax, desirous of a supply of albumen, nor consequently does it afterwards enter as a new inmate into the thoracic chamber. There are many other subjects of enquiry connected with the present, which in the absence of experience no one could follow out or solve, unless he were under the influence of a divine inspiration. The foregoing remarks we may apply also to the more imperfect animals, which before they see the light are nearly complete and consolidated in all their members ; and when these have attained to sufficient firmness, are immediately born to all the knowledge and intrinsic necessities of life belonging to their nature ; while we human beings are obliged to be taught what pertains to us through regular and lengthened periods ; that is to say, if we are allowed to complete our state.

296. *All the circumstances here recorded are most plain proofs of an infinite and omnipotent divine Providence.* Most stupendous is the order and connection of all things in the world and its three kingdoms. All things flow from an end, through ends, to an end. There is a most universal providence in the veriest particulars, to recount the arguments in proof of which, would be to impose an impossibility upon the most untiring tongue by reason of the infinite evidences with which creation overflows. To be lost in silent astonishment, therefore, at this display of Divine Wisdom, is more becoming our nature, than to overburden ourselves with proofs of its existence. In all the heavens there is nothing, throughout the whole earth there is nothing, but exhibits in most palpable signs the pre-



sence of a superintending Deity ; so that he who sees nothing in all these evidences, is blinder than a mole, and viler than a brute. Hence all those miracles that I have predicated of the formative substance (n. 248—271), are really due to the Divine Providence, who is the Author and Builder of all nature, in whom we live, and move, and have our being ; and who has so communicated principles to the principles of things, that everything flows in this provisory order, and from him and under him exists in its relations, and in its respect of ends.

297. But since in this Divine Abyss there is nothing but what is eternal, infinite, illimitable, supereminent, holy—away and away, we exclaim, with reason and philosophy, which long before they arrive at the verge of this fathomless deep, fail, and are forced into silence from the inability of language, and lose at once the faculty of utterance and of internal representation (n. 256). They, then, who by the guidance of mental philosophy dare to attempt this abyss, become the devoted victims of their rashness ; they return as it were paralyzed and faltering, like persons who have looked over sheer precipices into the vast profound ; or else blinded, like those who have gazed upon the sun ; and ever after, as I have often deplored, some spot or shadow flits before the eye of their reason, which at all times is dull enough of itself, so that they are blind in broad daylight, and live at the mercy of their own phantasies ; a just punishment for their presumption.

298. All that it is lawful to do is to kiss the threshold, that we may know that there is a Deity, the sole Author and Builder of the universe, and of all things in the universe, who is to be revered, to be adored, to be loved ; and that the providence of our reason is respectively nothing, while the providence of his wisdom is all in all. But what his Divine Nature is ; how he is to be worshipped ; in what way he is to be approached ; by what means he is to be enjoyed,—this it has pleased him, immortal glory be unto him, to reveal in his holy testaments and oracles. Only supplicate his pardon, use the appointed means, weary him with prayers, speak from the soul, not from a heart covetous of the world, and surer than certainty he will open to you the sanctuaries of his gracious favor.

299. It will now be desirable to reduce the general truths adverted to in the induction, into a compendious form, or to collect the various members that lie scattered through the present chapter, and to unite them into one body. This we shall do by explaining the genuine mode of formation, so far as we are enabled to explain it by experimental research. We shall introduce the subject by first stating the diversities and origins of those motions that nature has inscribed on her own substances, or to which she seems to have devoted herself. There are three species of motion; viz., local or translatory, undulatory or modificatory, axillary or central; there is, moreover, animatory, or alternately expanding and contracting motion: to this may be added conatus or effort, which is a perpetual tendency [*spirans*] to motion. Now, unless these things are first distinctly evolved and clearly understood, we shall but enquire in the dark what nature with her forces is and means,—that nature so often invoked by us in the various kingdoms, and in the animal kingdom especially: or by what necessity the more solid substances, which, as we said before, are formed in motion and for motion (n. 169), are born, act, react and concur, suitably to the peculiar activities of the fluids.

300. I. The subjects of local and translatory motion, as also of continued undulatory and modificatory motion, were treated of above, n. 169—174. I shall therefore omit any further exposition of them, and proceed to *animatory motion*, a kind of motion most familiar in the animal kingdom. *Animation* is the alternate intumescence and detumescence of a viscus, part, or individual; hence it is the origin of translatory-local motion, and consequently of undulatory or modificatory motion: as in the brains, lungs and heart, which are therefore termed the three general fountains of motion (n. 279). For in order that fluids may be translated from one place to another, it is requisite that there be an animatory reciprocation in their first origins, from which they may issue.

301. Now provision is made by a singular ingenuity and coördination of parts, that all the fluids shall be excited by means of animation to their living motions, and afterwards to those that are analogous to living motions; that is to say, to modificatory motions. Thus in the heart provision is made by a



wonderful carrying round of muscular fibres, from the base obliquely to the right and obliquely to the left, toward the apex of the cone,\* where they are continued round in a kind of perfect spiral and helix : and this, not in order that by such volutions the heart may twist and untwist spirally, but in order that it may with greater ease simply expand and contract. The case is the same with the cerebrum, where the congeries of the cortical substances, or the cortical tori, discriminated by winding furrows, make a surface by performing spiral convolutions. But all the parts, as well as each part in particular, have their planes, axes, and centres, and so are prepared for motion, in order that there may be a reciprocal respect of the planes by the surfaces, of the axes by the planes, and of the centres by the axes : and this, not with a view to enable the cerebrum to twist and untwist spirally, but to enable it to become more easily unfolded, that is, to enable it more easily to animate ; hence all the parts of the cerebrum are most ordinately located in the stream of this motion, as shewn above (n. 281). The cerebellum again has its surface discriminated in such a manner, that everything in it has the exactest relation to its axes and centres, nay, to its poles and cynosures ; while within the surface every part is so knotted up, that when a single part animates, so does the whole, and this so easily, that it evolves and involves itself and its coil almost spontaneously, as will be seen in the Parts on the Cerebellum : and this is not with a view to its performing a spiral mode of gyration, but that nothing may prevent it from flowing into reciprocal expansions upon the agency of the slightest force. Such then is animation in the living body, and such is its mode ; so that when the least subordinating force or life is once begun, animation is continued without any difficulty, and consequently the fluids are propelled from their starting-places to their destined goals. Animation then, considered in itself, is a local motion, but one that is reciprocal in the same place, and in the same sphere ; for which reason it is the fountain and origin of the motion of the fluids, which terminates in undulatory or modificatory motion.

302. But such simple animation, or intumescence and detu-

\* Versus conum.

mescence, exists only in compounds : let us now see what kind exists in more simple or less compound substances, in which animation is far more perfect ; for in passing from compound to simpler substances, nature exalts herself, as I have frequently indicated above. From the principles which I purpose to lay down in the doctrine of degrees, it follows, that the less compound or higher substances are not simply expanded, but are unfolded and folded by spiral twistings and untwistings ; although in this way expansion and animation undoubtedly arise, but far more easily than they can be produced in compounds (n. 101).

On the other hand, in the most simple substances the spiral or helix is perpetual, and there is nothing whatever that does not tend to animation in the most perfect manner ; and hence the natural spontaneity that is attained only in the purest substances of the kingdom. This we are taught by the doctrine of degrees to which I have adverted ; and moreover we see a kind of effigy of it presented in the heart and brains, and in the conglomeration of their parts, on which latter subject I have just spoken (n. 301).

303. The question now is, what and whence is axillary or central motion ? and what and whence is conatus ? We answer first, in regard to *axillary motion*, that if any substance, or little volume of substances, twist and untwist in a spiral, that is, in a perpetual circle, there will follow, from the action of the same principle, an axillary circumvolution, as in fluid parts, or in parts not connected to, or continued with, any adjoining substance (n. 101). Thus a spiral expansion being granted, we grant upon the same principle an axillary gyration. In like manner we grant also, in still more perfect substances, a *central gyration*.

304. We answer secondly, in regard to *conatus*, that if the animation of the brain be impeded by pituitary fluids intervening between the membranes, medullary fibres, or other plicatures, or by any substances anywhere inflamed or indurated, then instead of active [*vivæ*] animation there arises a conatus toward it. In like manner in the heart, the moment its entrances are clogged, or egress from its right side into the lungs, or from its left into the aorta, is closed, the heart is in the effort



to become expanded, although the effort is unavailing till the impediments and resistance to expansion are removed. In like manner again in the higher, more simple, or perfect substances, there is a stop to spiral twisting and untwisting, or to perpetual gyration round a centre, on the occurrence of the hindrances and resistance proper to that degree; still however a conatus remains toward this motion, which is in fact restored as soon as the impediments are removed.

305. From these remarks it follows, 1. That conatus is the internal principle of animatory motion, and that when conatus ceases, animation also ceases. 2. That so long as substances are in axillary or central gyration,—in gyration round an axis, or round a centre,—so long also they are in a certain living conatus; and that nothing but resistance offered by the proximate substances can restrain this conatus from passing into such an animatory or expansile motion, as the proximate substances may permit. 3. That the conatus itself begins to die away, when the substance cannot any longer be brought into gyration round an axis or a centre. 4. That this conatus is the first moving principle of animation, as well as the last; for it effects animation; this animation effects a local motion of the fluids; this local motion of the fluids effects undulation; this undulation terminates in conatus; and thus returns again into its first principle. There is therefore a circle of motions from conatus to conatus, to which all motions tend as to their natural equilibrium. 5. All the substances of the atmospheric world, as well as all of the animal kingdom, are formed with a view to such a property and possibility of animation; and hence it is that we said, that they are formed in motion and for motion. These observations are only general. To obtain a solid conviction on the subject, we require an application of principles to examples, or to the facts of experience.

306. If it be asked, Whence is this conatus or effort? or what is the first natural power that causes the more simple substances of the atmospheric world, and the living substances of the animal kingdom, to be in a state of conatus? We answer, that it appears to be a subject too high to be an object of rational investigation; and yet nothing can be plainer, and this too upon the principle, that each simpler substance of the world

is a least volume, and a type of its larger volume, hence a least volume and type of its universe, as it exists in that degree (n. 156). For nothing general can exist in the fluent atmospheres without there being a similar particular, because it is out of singulars that nature makes the general, especially where singulars act most freely ; so that in the grand universe we may always contemplate the character of its minimal substance. In short, as the whole universe or great solar vortex (granting that there is one) revolves round a centre, so also does its smallest volume, a vorticle, or a part. As the whole of this great vortex is quiescent at its poles, so also is its smallest vorticle and part. As the whole of this vortex describes its greater circles, its equator and zodiac, in relation to its poles, so also does its lesser and least vorticle. As the whole vortex describes lesser circles in relation to the larger circles, so also does its least vorticle or part. All these motions are performed according to the irrefragable principles of geometry. As the whole vortex includes in its centre a most active sun, which gives the principle of activity to the universe, so also does a least vorticle or part include substances having a similar activity or gyration ; not much differing from that to which I have adverted on the subject of fire (n. 84). Such then is the origin of conatus, and such the first natural power that causes substances to be in a conatus to motion. Such now is primitive nature in her highest simplicity, perfection, and universality, the knowledge of which is the same with the knowledge of the universe of nature, and constitutes true physical and geometrical astronomy. Perhaps it will be better at present to defer any further exposition of primitive nature, since if I introduced sufficient illustrations, I might be digressing too far from my subject ; and on the other hand, if I did not, I might be considered as deviating from well-known experimental facts into obscure speculations.

If it be asked, whence is conatus and what is the first *natural* potency ? or if proceeding still further it be asked, whence is this first natural potency, or whence is nature ? The most eager for knowledge will I think be satisfied, if I say, that nature is a work called out of nothingness by the omnipotent God, from whom are all things, for whom are all things, and who is that He is. We can go no further than this, for the



wisest of mortals is he, who knows with certainty, that in divine things, he knows nothing beyond what is revealed (n. 297, 298).

307. II. We have hitherto spoken of the origins and diversities of activities: let us now proceed to the general mode of formation displayed by the chick in the egg. In the living point of the cicatrix there is a certain perpetual animation, which is afterwards manifested also in the circumfluent zones, and in the vesicles, as observed by Malpighi and Lancisi. But this animation when carried on in the purest substances, as in the living point, may be termed the analogue of an animatory motion or mode, or a mutation, or an active or living force, or the force of forces, or the first principle of the law of acting, or else simply a determining principle. Animation however is frequently confounded with conatus, whereas conatus is its first internal principle of acting, and may persist without a real expansion. But let us return to the first living point in the cicatrix. There is reason to believe that this point is in a state of animation, although the egg may not be incubated or submitted to warmth; for this first living point is inclosed in its own proper colliquamentum, and this is distinct from the albumen, so that nothing impedes its acting according to the conatus; for if the central or axillary gyration cease, then the conatus to animate ceases in a short time (n. 304, 305). Leeuwenhoek relates, that in the globules of blood he observed "another kind of motion, in that each globule gyrated round its own axis" (n. 29). Harvey says: "There is room to doubt whether before [the heart and even the auricles pulsate], the blood itself, or the spirit, has not in it an obscure palpitation, such as I have seen continue after death" (n. 246). Malpighi says: "I often kept the chick, and dried the yolk underneath it, and the pulsation of the heart continued without intermission for a whole day" (n. 242). Again he says: "I have often remarked, as a usual piece of nature's play, a motion present in the zones, by the coming and going of which, the areas and cavities of the carina were either enlarged or obliterated" (n. 243). Lancisi\* observed somewhat similar in the vesicles surrounding the head.<sup>x</sup> For if an animation such as I have stated lives in the

\* I cannot find this in Lancisi, nor is it clear what is meant by "the vesicles surrounding the head."—(Tr.)

blood, the heart, the zones, and the vesicles, why should it not in the least living point, since in its own proper colliquamentum it enjoys the complete liberty of animating and of living. In these minutest points, the inappreciable quickness of the animatory action causes it to appear continuous, and thus to assume the semblance of rest; a circumstance which is very common in the case of those revolving bodies whose motion is too rapid to be followed by the eye.

308. The albumen of the egg cannot be actuated by this living point until the warmth of incubation relaxes the coherence of the parts, or removes their torpor, and excites a certain species of activity. When the albumen is in this state, then, by its aid, the point which is in a perpetual state of animation, is enabled to extend the sphere of its activity further, inasmuch as through the medium of a fostering and moderate warmth, the several parts in the egg are released from their bonds, and most highly prepared, and obeisant to the living activity. How this activity pours forth in the purest substances of nature, as it were spontaneously from a given centre to all the peripheries, is very evident from the modulation of sound in the air, and the modification of images in the ether; for in highly elastic bodies no impressed force is ever lost, but continues similar to itself, and in an effort to attain its ultimate destination. That there is great elasticity in the parts of the albumen, is evident from the experiments that have been made respecting it.

309. The living point then, by means of its animation, exerts and diffuses its forces into the albumen, now excited by warmth, and no longer torpid: for nothing resists this point, or makes any effort against it; but all the various parts are called into existence conformably to its determinations, being as it were obedient to its orders. Thus there is an abundant conflux of things conformable to it acting at the centre, and forces are multiplied; whence the animation takes a plural form, or if I may so speak, becomes compound; consequently the sphere of its activity is extended, and continues to extend as the chick passes through its stages of composition or epochs of development (n. 273—278), and the action penetrates finally into the yolk. “*On the completion of the 6th day,*” says Malpighi, “. . . the umbilical vessels issuing [from the closed abdomen] were



partly sent to the thin albumen surrounding the yolk and amnion, partly into the yolk itself. . . . *At the end of the 7th day, . . . the umbilical vessels, coming outwards, were elongated through the yolk and albumen*" (n. 242). Thus it appears, that perpetual animatory mutation arises primitively from perpetual conatus; the expulsion of the purest fluid to its destined locality arises from animatory mutation, and in the place of the fluid expelled there is a fresh influx of fluid for the purpose of maintaining the general equation and equilibrium (n. 227): the modification of the fluid arises from its expulsion,—the modification extending to the peripheries determined by the centre; and a central or axillary gyration of the individual parts arises from this modification; and so again we have a conatus to a similar animation. Thus the universal circulation is carried on, by means of which everything in this limited universe is continued, supplied with moisture, nourished, renovated, formed, actuated and vivified (n. 154).

310. It may now be seen, that this primitive animation or analogue of animation, is life in its general or common state, or rather that it is the living force, the *vis viva*, as it is called, that is wont to be ascribed to all the substances existing in the world, which are in a state of animation similar to the foregoing. But considered in itself this animation is not properly animal life, for to animate is not the same as to live, but determinately and distinctly to animate, is to live; and the more determinately and distinctly, the more and better is the life. Thus sensitive life raised to higher or superior powers is the verimost life.

311. But how the representative determination can effectively produce these first and successive mutations in the formative substance and force, or in the soul, and what the distinctive nature of this determination is,—these are subjects which cannot be easily treated without a mathematical philosophy of universals and a doctrine of degrees; for without some such aid we should find that to bring the question within a short compass would only be to make it obscure, since nothing adequate can be predicated of the soul by means of the formulas of the lower degrees. Yet inasmuch as all the superior powers are related by analogy to the inferior, and *vice versâ*, and we may be allowed from the

inferior to form inductions with respect to the superior as the more eminent ; since one may be illustrated by the other, as by examples, I will select for comparison the systolic motion of the heart and the systaltic or animatory motion of the brain. Thus, for instance, unless the sanguineous stream were most exactly determined from the heart through the arteries into the motive fibres of the muscles, and into the corresponding fibres of the glands, the economy of the body could not exist, nor the animal live in action (n. 131). The blood would be only an indeterminate fluid ; its motion indistinct, general, and incapable of life. Again, unless the brains were most accurately discriminated into cortical tori, and the cortical tori into spherules, by which the medullary and nervous fibres might be excited, their animation would be a mere indeterminate motion, and there would be no life ; because to animate is not the same as to live, but to animate distinctly and determinately is to live. In like manner there would be no corporeal life unless in the body, one thing lived in complete subordination to the other. So also in regard to the higher substances of nature, unless they had representative determinations, life could never be predicable of them. When however they have their determinations, then their animation is not a mere motion but a general or common life ; for in order to the existence of a distinct particular, a common or general is required. Every point then of the spirituous fluid is to be conceived of as most perfectly determined, or else, if you please, represented, or having within it determinations which are representative of its own little world ; and when such is the case, this point is a determining or representing point, which fact constitutes its life. But all these things cannot exist from themselves, or subsist by themselves ; they must derive their being from another, who alone is from himself, and from whom is the universe, and all that it contains.

312. III. It was shewn above, that in the work of formation the spirituous fluid is the first cause, the purer blood the second, and the red blood the third (n. 271, 272) ; and thus that the chick in the egg passes through three different stages. We now come to shew, what are the passages traversed by the first fluid, what by the second, and what by the third ; there being distinctive passages most ingeniously devised for each of these fluids.



Vesicles are formed, for instance, which surround the tender brain and spine; these vesicles again are surrounded by fluent zones; and all these, having derived animation from the first living point, themselves also animate. Thus whatever nutritive substance lies in the albumen of the egg, receives modifications [*commodificatur*] which are in most perfect accordance with the animation and determination of the before-mentioned living point, so that nothing but what is adequate to it seeks this point as its centre. In the first stage of formation, imperceptible pores are prepared, which lead through the very surfaces of the vesicles; and through these pores the spirituous fluid is conducted which has thus been modified [*emodificatum*] out of the egg: it is next conducted through the interiors of the vesicles, and so on, until from want of nutritive juice these vehicles become obscured, dried up, obliterated and deciduous. The great tendency of the albumen of the egg to vesicular forms, appears on its being well shaken, a process by which it is so remarkably thrown into froth, that one would be disposed to say it consisted of scarcely anything but vesicles, in which the fluids that are to minister in forming the chick are in beautiful order in their several allotted places. But it is worth while to extract from Malpighi's descriptions that part which relates to the zones and vesicles, so that we may be able to comprehend in one simple view the process of formation. The following is a summary of his statement.

313. At the end of 12 hours, the carina, defined by white zones, exhibited for the first time the orbicular vesicles of the vertebræ, situated at intervals on either side; the series of white orbicular sacculi representing these parts, or of vesicles contiguous to each other, extended downwards, and beset the stamina of the spinal marrow. The author's Figures shew that there were three vesicles belonging to the head, contiguous to which the others came on, surrounding the spine. After 30 hours, the zones, united together, formed various spaces or areas, and surrounded the vesicles of the brain and the continuous production of the spinal marrow. About the 36th hour, the highest vesicle in the head was distended with a lead-colored ichor; the other vesicles were generally smaller, and full of a pellucid fluid. After 38 hours, three vesicles might be detected in the head.

After 40 hours, the vesicles were not so evident. The zone was narrowed or contracted, and as usual surrounded the brain and spinal marrow. In 48 hours, the vesicles filled the curving head; the sacculi of the vertebræ were still more apparent, forming longitudinal lines. At the end of 2 days and 14 hours, the vesicles of the brain were supplied with blood-vessels. At the end of 3 days, there were five vesicles turgid with fluid, which represented the brain. At the top of the head there was one of considerable size, furnished with vessels, and in shape like a hemisphere, and which on the subsequent days was in a manner divided into two. In the occiput there was a kind of triangular vesicle, but the deep region of the sinciput was occupied by an oval vesicle, close to which were placed the other two, completing the five. At the end of the 4th day, the five vesicles constituting the brain were still more conspicuous, and had come nearer together, and when lacerated, let out an ichor or fluid. The round bodies representing the vertebræ were increasingly protuberant. The cristate vesicle was filled with a cinereous and somewhat concrete substance. Not far from thence in the occiput, at some little depth, the second, or the vesicle of the cerebellum, was placed, and to it was subjoined a portion of the spinal marrow. In the anterior part, at a greater depth, lay the third vesicle, and the other two formed the termination or apex in front. At the end of the 5th day, the head was large, and the cristate vesicle was seen, replete with a filamentary substance: the cerebellum was attached to this vesicle. Anteriorly the two vesicles of the apex were seen with the deeper vesicle placed above them. When the 6th day had elapsed, the same vesicular structure as heretofore was observed in the brain: the cristate vesicle was furnished with a large vessel, and the vesicle next to it was concealed, and could not be brought into view without denuding and separating the cerebrum. The great cerebral vesicle was in a manner double, divided by an oblong fissure, and affording perhaps a place for the falx, and when lacerated no fluid now escaped. The two anterior vesicles of the brain, less protuberant than before, were somewhat obscured by the incipient growth of flesh. The vesicle above and between them, was almost lost to view, as was the case also with the fifth vesicle placed in the occiput. At the end of the 7th



day, the cristate vesicles were composed externally of a fibrous substance; while their interior cavity was full of a fluid or ichor. The brain had become more protuberant, and was contained in the usual coverings; on lacerating which, the ichor so lately fluid was found to have concreted into solid filaments. After the 8th day, the hitherto separate vesicles were united, and constituted two eminences, containing the ventricles. After the 9th day, the cristate vesicles of the brain, which terminate in the origins of the optic nerves, were smaller and more deeply seated, and inclined to the sides. The anterior vesicles were seen, and likewise the origins of the optic nerves, running from the cristate vesicles to the eyes. A portion of the infundibulum produced from the contiguous vesicle, gave support and continuity to the brain. (Malpighi, above, n. 242, 243.) See also the author's descriptions of his several figures.

314. The following inferences in relation to our present subject may be drawn from this account of the vesicles. 1. The living point produces by its animations all the vesicular substance of the fluid of the egg; hence vesicles around itself, and zones around the vesicles. Thus the work of formation is gone into in regular order and keeping. 2. All these vesicles and zones, animating correspondently to the determination of the first living point, modify and call forth no other than an adequate fluid, however such fluid may be dispersed throughout the sphere of the egg; and as soon as the living point, by the force of its animation, determinately expels its fluid, a similar other fluid comes in its place, from the peripheries of the egg, for the purpose of preserving the general equation (n. 227), and so on continually. 3. The fluid which thus succeeds, forms passages for itself through the vesicular surfaces, which are so many spheres that are adequate to it; and as soon as these passages are formed, they are alternately expanded and constricted by the same general animation; whence a fresh supply of fluid is constantly elicited from the albumen in a way not unlike that in which the blood is elicited by the brain through the medium of a similar animatory motion; on which subject, see n. 349, and Part II. In this manner there is no supply of anything but what is suitable and determined. 4. The vesicles of the brain are kept contiguous to the vesicles of the spine, in order that

they may act at once conjointly and separately ; lest anything should proceed otherwise than in harmony, or otherwise than under the influence of the first and highest vesicle. For this reason also common or general zones surround all these vesicles. 5. These vesicles are altered as formation proceeds, and this, in respect to situation, number, magnitude, form, and consistence ; thus they become separated, are drawn in deeper, are divided, are pierced with wider pores, and ultimately with pores for the red blood ; they are covered over with fibres ; they become concealed, juiceless, and obliterated, so that at length they are separated as useless, while all the other parts are invested with their proper integuments, and so perfected as to be able to perform their work of themselves, and without the assistance of vesicles. But this is effected successively, as the members are brought into play and adapted to uses ; such members, for instance, as the cerebellum, the ventricles of the cerebrum, and the infundibulum ; the thalami of the optic nerves, and also the heart, which is primitively a vesicle. Thus all things are carried on most distinctly (n. 248), and are formed successively for use (n. 249, 250, 251). Thus the formative substance draws the thread from the first living point, and afterwards continues it (n. 253). Thus the spirituous fluid is the first cause, the purer blood is the second, and the red blood is the third (n. 271, 272). The most pure fibrils are first produced, then the vessels of the purer blood, and finally the vessels of the red blood ; one of which is prior to the other, and then as they are compounded, one acts with the other (n. 272) : not to mention a variety of other things of which I have spoken above, and which here also receive confirmation, especially the position that the first animation is most highly determined, and that suitably to its representation causes flow in a provisory and given order to the ultimate effect (n. 260, 311). 6. Moreover, a certain most pure fluid enters the red blood as its principal substance, and constitutes its vital essence (n. 37). To this is added various salts that enter into the composition of the globules of the red blood (n. 43). The order in which this is effected is sufficiently evident from a contemplation of the progress of formation ; for volatile, ethereal, sulphureo-saline substances are attracted from the albumen as well as from the ether



through the pores of the shell (n. 53), and then the grosser elements are attracted in order that the red blood may be tempered, copulated, and perfected (n. 50, 91); whence the sphere of activity becomes extended to the yolk itself, where these things lie in reserve for this ultimate use; while at the same time the shell is wonderfully opened to the atmosphere, in order that it may be replenished from this source in addition, according to the experimental facts related by Bellini in his treatise, *De Motu Cordis*, prop. ix.\* 7. We may hence infer that the composition and recomposition of the blood in the veins is effected in like manner, that is, through the medium of vesicles (n. 199). This conjecture is favored by the nature of venous blood; by its distension when placed in an exhausted receiver; by the difference of its nature from that of arterial blood; by the extremely quiescent state of the veins (n. 190—197); and by this consideration, that in order for what coexists to subsist, it must perpetually exist by the same modes by which it existed originally, so that subsistence may be perpetual existence.

315. These are all the inferences which I design to draw from the narrative presented to us upon the subject of the vesicles, so far as it relates to my present subject. The facts which are evident are indeed comparatively scanty. It is only a few drops that we are able to snatch from the fathomless ocean, and from these, obscure as they are, is all our wisdom derived. Still whoever wishes to admire the Creator in his work and in the universe of nature, has only to enter into the animal kingdom, as also into himself, and there to contemplate the causes of things with a desire to trace them from their primary source, and fresh wonders of wonders will every moment be bursting upon his view, even though his life should last a hundred times longer than Nestor's, and he should occupy the whole of it in investigating the mysteries of nature.

\* *Opuscula Aliquot*, p. 52; 4to., Lugd. Bat., 1696.—(Tr.)

## CHAPTER IV.

ON THE CIRCULATION OF THE BLOOD IN THE FŒTUS; AND ON THE FORAMEN OVALE AND DUCTUS ARTERIOSUS BELONGING TO THE HEART IN EMBRYOS AND INFANTS.

316. VERHEYEN. “The blood of the fœtus not only circulates through its own proper parts, as in adults, but it is also sent through the umbilical arteries to the placenta, a small portion being distributed to the membranes on the way: and it returns from the placenta through the umbilical vein to the vena cava, and so to the cavities of the heart. This is the first difference between the circulation of the blood in the fœtus, and the circulation after birth, when the placenta is separated, and the blood no longer circulates beyond the limits of its own bodily system; and thus it is that at birth the umbilical vessels are cut away and thrown aside, as being of no further use. The blood returning through the umbilical vein, is mixed with the rest of the blood in the vena portæ, from the sinus of which a large portion of it is carried to the vena cava through a short venous tube, [the ductus venosus,] which is peculiar to the fœtus, and falls into the vena cava immediately under the diaphragm. . . .

“Another peculiarity in the foetal circulation is observable about the heart, and as in the former case, involves the existence of special channels or passages; by means of which the larger part of the sanguineous mass passes in fact through the left ventricle of the heart and through the aorta, without previously going through the lungs. These special passages are the foramen between the vena cava and the pulmonary vein, and a short arterial tube, [the ductus arteriosus,] between the pulmonary artery and the descending aorta. The foramen is situated between the inferior vena cava and the pulmonary vein; opening into the former immediately below a tubercle that lies adjacent to the first division of the vena cava; and into the pulmonary vein near the left



ventricle. It is called from its figure the foramen ovale. It is so large at first towards the vena cava as to exceed the aorta itself in size, but where it terminates in the pulmonary vein it is somewhat narrower. In the upper part, towards the right ventricle, it has a raised border to prevent the blood from easily passing it by ; but at the lower part it is comparatively flat and even, to make the entrance of the blood more easy. Before the outlet of the foramen in the pulmonary vein, there is a large valve, which towards the lungs is attached to the wall of the vein, but towards the ventricle of the heart is entirely free. This valve serves principally to prevent the blood which passes through the foramen from the vena cava, and the blood which passes from the pulmonary vein towards the left ventricle, from impeding each other in their course. Through this foramen then a large portion of the blood of the vena cava that would otherwise pass to the right ventricle, runs of necessity to the left : immediately, when the left ventricle is open, and when it is not open, mediately through the corresponding auricle, from which the foramen almost directly opens. I say a large portion of the blood, this being sufficiently indicated by the size of the foramen ; although what the actual quantity is, I believe it to be impossible to determine. But perhaps a doubt may exist . . . as to how the blood of the vena cava can pass into the pulmonary vein through a simple foramen, for it may be thought that the two veins are distant from each other, as being adjacent to different cavities of the heart ; hence that in order for the blood to pass from the cava to the pulmonary vein, a tube must be required, to effect a communication between them. But this doubt will cease, if we only consider that these two veins are inserted into the ventricles on the posterior part, so near together that their coats join, and form as it were a complete wall perforated by the foramen ovale.

“ The ductus arteriosus arises from the pulmonary artery, near its commencement and immediately before its division into a right and left branch : in fact, we may say that this artery divides into three branches, namely, into the two already mentioned, and into the very canal of which we are speaking. This duct, canal, or tube, terminates in the descending aorta not far from its commencement. It is of much larger calibre than the great branch of the pulmonary artery ; in fact, nearly one half of the whole artery is expended upon it. A great portion of the blood sent from the right ventricle of the heart into the pulmonary artery, passes immediately through this tube into the descending aorta, and is distributed by the twigs of the latter through the lower parts of the body, and through the secundines.

“The circulation in the foetus is therefore performed as follows : A great part of the blood passes from the inferior vena cava near the heart, through the foramen ovale into the trunk of the pulmonary vein ; thence into the left ventricle, immediately if the ventricle be open at the time, but through the left auricle if the ventricle be not open. But that portion of the blood of the inferior vena cava that does not pass through the foramen ovale, runs together with that which comes through the superior vena cava, into the right ventricle, in part immediately, and in part mediately through the auricle, just as in ourselves : from the right ventricle it is expelled into the pulmonary artery, and a great part of it passes thence immediately through the ductus arteriosus into the descending aorta ; the other part pursues its course through the pulmonary arteries and veins till it comes to the left ventricle, which it enters, sometimes immediately, and sometimes mediately through the auricle ; and then, together with the blood that arrives at the same moment through the foramen ovale, it is driven into the aorta by the constriction of the ventricle. But since the descending aorta is much occupied by the blood conveyed through the ductus arteriosus, it is evident that it cannot receive much blood from the left ventricle, and therefore that nearly the whole, or at least by far the greater portion of the blood of this ventricle, is distributed through the superior parts of the body. The blood that passes through the descending aorta, circulates not only through the inferior parts of the foetus, but also through the secundines, as we before observed. . . . And although the pulmonary arteries after their division are collectively somewhat more capacious than the ductus arteriosus, it does not therefore follow that a less quantity of blood passes through the latter than through the pulmonary arteries ; but rather a larger ; for the transit of the blood through the lungs of the foetus is exceedingly difficult, inasmuch as they are collapsed by reason of having no respiration, and therefore considerably compress their blood-vessels. . . . (*Corp. Hum. Anat.*, lib. ii., tr. v., cap. xix.)

“The foramen ovale remains longer open towards the ventricle and auricle than on the other side, as I have sometimes observed in the human subject, and very frequently indeed in brutes. . . . Now as this foramen is closed on the side of the pulmonary vein, but not on the side of the vena cava, therefore we find that in the latter situation there is always a large sinus left to mark the place of the foramen ; and this sinus is found even in old subjects ; nay, even in the bodies of those who have died of old age.” (*Ibid.*, cap. xx.) *Corp. Hum. Anat.*, lib. i., tab. xx., fig. 11, represents the vena cava opened, shewing the foramen ovale,



and beside it a tubercle (seen also in some animals) near the orifice of the coronary vein, which orifice in the sheep is said to be common to the coronary and the bronchial vein.

317. LOWER. “It remains for us to observe, that while the foetus is in the womb, where respiration cannot be carried on freely, and where consequently it is not necessary that the whole of the blood should pass through the lungs, it is wisely ordered that the greater part of the blood shall be carried in another direction. For in the foetus, immediately below the tubercle above mentioned,\* a foramen, called the foramen ovale, opens into the nearest pulmonary vein, just before the entrance of the left ventricle ; and through this foramen, the greater part of the blood returned to the heart by the vena cava, immediately before the entrance of the right ventricle, is poured into the pulmonary vein, and together with the blood that has served for the nutrition of the lungs, is sent into the left ventricle. But lest the blood should return the same way, a peculiar membrane is attached all round, except at the bottom, to the margin of the foramen, and loosely hangs like a veil in the trunk of the pulmonary vein, falling below the inferior border of the foramen ; so that it easily yields to the blood coming from the vena cava, and opens the passage as it were spontaneously. On the other hand, when by any chance the blood is urged to return from the pulmonary vein into the vena cava, this membrane, by the first impetus of the blood of the pulmonary vein, is closely applied to the side of the foramen, and thus effectually prevents the return. . . . And as there is as yet no necessity for all the blood that flows into the right ventricle, and thence into the pulmonary artery, to pass through the lungs, so we find a provision made to divert a part of it from the lungs, in the existence of an arterial canal running from the pulmonary artery to the aorta. Thus the blood expelled from the right ventricle is transmitted for the most part through this canal into the aorta, and distributed with the rest of the blood throughout the body. But after birth, and when respiration begins, the foramen ovale and arterial canal . . . gradually and daily diminish, until at length the former is quite closed, and the latter degenerates into an impervious ligament.” (*Tractatus de Corde*,† &c., cap. i., p. 54—56 ; 12mo., London, 1669.)

318. HARVEY. “The first contact and union between the vena cava and the venous artery,‡ (which takes place before the cava opens into the right ventricle, or gives off the coronary vein, a little above its

\* The tuberculum Loweri.—(*Tr.*)

† The reader will find the plates to Lower’s Treatise very valuable for assisting his comprehension of the authors cited by Swedenborg in this chapter.—(*Tr.*)

‡ The pulmonary vein.—(*Tr.*)

egress from the liver,) exhibits a lateral anastomosis, that is to say, a large, open foramen, of an oval figure, and pervious from the cava into the venous artery [so called by the ancients]: so that the blood is enabled to flow forth freely and abundantly through this foramen, as through a single vessel, from the vena cava into the venous artery and left auricle, and thus into the left ventricle. Moreover, in this foramen ovale, on the side towards the venous artery, there is a thin, firm membrane, serving as an operculum or cover, and larger than the foramen; and which afterwards in adults so covers the foramen, and unites on all sides so effectually with the surrounding parts, as entirely to obstruct and almost to obliterate the passage. This membrane, I say, is so placed, that while it loosely falls in upon itself, it creates a passage to the lungs [*i.e.* to the roots of the lungs (*imos pulmones*), or rather to the trunk of the vein issuing from them]\* and heart, is laid back, and yields to the blood coming from the cava, but prevents the blood from flowing back again into the cava. . . . The second union is of the arterial vein;† it takes place after that vein, issuing from the right ventricle, divides into its two branches, and reckoning these two branches as trunks, this union is a third trunk and as it were arterial canal, leading and opening obliquely into the great artery; so that in the dissection of embryos we see as it were two aortas, or two roots to the great artery arising from the heart.” (*Exercitatio Anatomica de Motu Cordis*, cap. vi.)

319. NEEDHAM. “In connection with the heart of the fœtus we meet with two anastomoses [which are obliterated after birth]; namely, the foramen ovale and the canalis arteriosus. . . . The former opens from the right auricle into the end of the pulmonary vein, or the beginning of the left auricle; in short, into the confine between the two: and pours the blood into the left ventricle without allowing it to approach the right. The canalis arteriosus begins a little beyond the sigmoid valves in the pulmonary artery, and runs transversely to the aorta, being somewhat smaller than it, but certainly larger than the arterial vein from this point to the lungs. The canalis arteriosus is more capacious near the heart than near the aorta. It is evident from the above circumstances, that this canal is a broad or royal road by which the circuit of the blood is performed so long as the lungs are unopened.” (*Disquisitio Anatomica de Formato Fœtu*, cap. v., p. 107, 108; 12mo., London, 1667.)

\* The words in brackets in n. 318 are interpolated by Manget, from whose *Theatrum Anatomicum* Swedenborg evidently copied this extract.—(*Tr.*)

† The pulmonary artery.—(*Tr.*)



320. MUNNICKS. "In the ascending vena cava, near the heart, there is a large mouth, now generally called the foramen ovale, through which a passage leads from the vena cava to the pulmonary vein, and which is guarded by a membranous valve towards the latter vein. There is also a short canal running from the pulmonary artery to the aorta, and called *canalis arteriosus* by reason of the thickness of its coats. Thus the blood that comes through the ascending vena cava from the lower parts, passes through the foramen ovale into the pulmonary vein, and all enters the left cavity of the heart. But the blood that comes through the descending vena cava from the upper parts, is all sent into the right ventricle; whence it is expelled partly through the pulmonary artery into the lungs, and pursues its course through the pulmonary vein to the left ventricle; and partly through the pulmonary artery, into the *canalis arteriosus*, and by this route into the aorta. In process of time nature gradually obliterates both these passages, namely, the foramen ovale and the *canalis arteriosus*, and never opens them again in adults, unless serious obstructions occur in the ordinary channels. The foramen ovale is closed by no other means than by its valve, which in point of substance, tenuity and translucency, always retains its original valvular character. The lungs in the fœtus are comparatively red, and during the early period of formation very heavy and dense; but from about the third month they become daily thinner and lighter, and are more expanded at birth, when the fœtus is mature: . . . nevertheless when placed in water, they sink," &c. (*De Re Anatomica Liber*, n. 34., p. 88—90; 8vo., Utrecht, 1697.)

321. MANGET. "Mery grants that the blood is derived from the pulmonary artery into the aorta through the *canalis arteriosus*; . . . but he denies that the same blood, in the natural course, is again conveyed through the foramen ovale from the vena cava into the pulmonary vein; but thinks rather that by a change in the laws of nature it flows back from the pulmonary vein into the vena cava, to supply the absence of air in the fœtus. . . . Littre asserts that he found the foramen ovale open in a man of forty, and this, in such a manner, as to allow a passage from the pulmonary vein to the vena cava, but not *vice versâ*; for the orifice of the foramen was thrice as large towards the pulmonary vein as towards the vena cava; from which it seemed to him that the first impulse of the blood must be on the part of the pulmonary vein, and that there must be an introduction of the blood into the vena cava." (*Theatrum Anatomicum*, tom. ii., p. 195; fol., Geneva, 1716.)

322. MORGAGNI. "Does the blood flow through the anastomosis which I before described as existing in the fœtal heart, from the vena cava into the pulmonary vein, according to the common opinion; or

does it pass from the pulmonary vein into the vena cava? I investigated this point in the foetal calf, . . . and made the following observations. In the first place, the valve in this situation was so large and remarkable on the side towards the pulmonary vein, that I do not see how those who refuse to call it a valve, can consistently call any other structure in the body by that name. On applying a probe to it on the side next to the vena cava, the probe passed on without any difficulty of its own accord into the pulmonary vein. On the other hand, when I tried to pass the probe from the pulmonary vein into the vena cava, the valve presented an impediment, and the probe did not glide on with the same freedom and facility. Among the various causes of the delay and impediment thus experienced, were certain little cords connecting the border of the valve to the front part of the pulmonary vein, and which I find were known to Ridley, who afterwards looked for them in vain in the human foetus, as I did likewise in the foetus of the dog. Among these cords there was one much thicker than the rest. They were all exceedingly like those fibres by which the borders of the mitral and tricuspid valves are attached to the columns of the heart. And there is nothing, so far as I know, to militate against the idea, that they correspond also in function and office to those fibres; that is to say, are stretched during the diastole of the auricles, and drawing upon the valve, admit the blood, but on the other hand are let back during the systole, and relaxing the valve, allow the blood to close the passage, lest after having come from one of the auricles, it should immediately flow back again into the same. Be this as it may, certain it is that these fibres would not be placed on the side next to the pulmonary vein, if the valve was not meant to allow a passage into this vein, but into the vena cava. (*Advers. Anat. i.*, n. 20.)

“Although, Manget,\* you have brought forward four passages from different writers, on the subject of the arterial tube, yet from not one of them can the reader understand into what part of the aorta the blood is carried by that tube. Who indeed could conjecture from your citations, that it is carried into the beginning of the descending aorta, after that vessel has given off all its branches to the superior regions: a fact from which certain ingenious inferences have been drawn by recent anatomists. . . .

“We have very frequently seen, that that part of the valve which extended beyond the anterior and inferior margin of the foramen ovale in the foetus, even in old subjects was not only not united to the wall of the pulmonary vein, but presented the appearance of two or more

\* See the note to p. 83.—(*Tr.*)



unequal sacculi, or oftener still, of one large sacculus, (or if you please, of a sigmoid but narrow valve, or as Verheyen calls it, a large sinus,) the orifice of which sometimes looked downwards, and frequently forwards; and admitted a large probe, and even the end of the handle of a scalpel, between it and the wall of the vein, to such a depth, that what Verheyen saw in calves of different ages appears to be true also in regard to man; namely, that the valve, while it is united to the wall of the pulmonary vein on the side facing the lungs, still increases and is extended where it looks toward the heart. I have most certainly observed that nearly the whole of that part of the valve which was still loose, had become much thicker and firmer than it was in the foetus. At the very bottom of the sacculus, between it and the front and upper border of the foramen ovale, I have frequently seen a minute passage still open for the blood, and once of such a kind as to admit the point of the handle of a scalpel without any difficulty into the vena cava. This passage I found in a female subject, and the like also once in that of a male at least forty years old, in which case it was so wide as almost to admit the tip of the little finger on the side towards the vena cava; for the farther the passage went to the orifice of the sacculus, the more it contracted, and assumed the form of a conical tube. This last observation flatly contradicts that which you say that Littre had made in another subject; and the former observations seem to suggest a doubt, whether the orifice which Littre found to be ‘thrice as large towards the pulmonary vein as towards the vena cava,’\* did not belong rather to the sac which I have described, than to the foramen ovale itself; that is to say, whether the smaller opening which he saw in the vena cava, was the whole of the foramen ovale, or only a part of it still left open by the valve not being attached on every side to the border of the foramen: and whether the other larger opening that he saw in the pulmonary vein, was any other than what I have termed the orifice of the sacculus, and which it is true that I have generally found wider than the bottom of the same.” (*Advers. Anat.* v., *Anim.* xvi.)

323. FANTONI. “If the breast of a living dog be opened, and the ribs forced outwards, the lung collapses, and no longer admits the air. . . . The heart still beats, but in vain attempts to throw the blood into the pulmonary artery, for the latter is contracted; and in vain undergoes relaxation in order to receive the pulmonary blood into the left auricle. Both the vena cava and the auricle, as well as the right ventricle and the pulmonary artery, are swollen with the obstructed blood;

See above, n. 321.—(*Tr.*)

for scarcely any blood passes through the lungs during their continued state of collapse. Meanwhile, if air be thrown in through the trachea, all the operations of the parts will be beautifully restored ; the veins, the auricle, the heart, and the artery, will be seen to be emptied, and the lungs to be partly released from the old blood, and partly filled with new." (*Anatomia Corporis Humani*, &c., dissert. xiii., p. 339 ; 4to., Turin, 1711.)



#### INDUCTION.

324. FROM the anatomy of the chick in the incubated egg, it appears that the circulation of the red blood passes through three remarkable changes and vicissitudes. The first, when the primitive heart or punctum saliens propels the blood received, through certain vessels upwards toward the brains; and the brains express it downwards into the umbilical vessels. At this period the brains are the principal cause of the circulation of the blood.

The second change takes place when the aorta is extended downwards to the region of the abdomen. The blood is then carried away by the inferior vena cava, after traversing the cardiac vesicles, toward the brains; and thence it is carried down by the superior vena cava, after again traversing the cardiac vesicles, through the descending aorta into the abdominal region; from which it returns through the inferior vena cava as before. The circle which the blood thus describes, is as it were double, and reflex, but yet continuous. So long as this circulation continues, two motions must exist successively in the auricles, and two in the ventricles.

The mode and determination of the circulation in the united or conical heart, before the lungs begin to respire, is similar to the above. Thus the blood carried down from the brains through the superior vena cava into the right ventricle, is propelled therefrom through the ductus arteriosus into the descend-

ing aorta, and so into all the provinces of the inferior region. Then it ascends through the inferior vena cava, and is driven through the foramen ovale into the left ventricle, and from thence towards the brains; and so on continually: the heart itself distinctly determining the stream in both cases. This is the purpose of the foramen ovale and ductus arteriosus, without which such a circulation could not be carried on.

Thus before the blood is allowed to travel through the lungs from the right ventricle to the left, it is all sent to the brains previously to being conveyed to the body and its viscera. And lest the brains should be contaminated by foul blood, it is first passed through the liver, to undergo purification. But these things take place with a difference in oviparous and viviparous animals respectively.

The third change occurs after birth and exclusion. For the blood is then driven from the superior vena cava and from the inferior vena cava simultaneously, into the right auricle and ventricle, and traversing the lungs, into the left auricle and ventricle, and thence into the trunk of the aorta: from which the brains take out and attract no more blood than their state demands. At this time there are no longer two successive motions in the auricles and two in the ventricles.

Thus, as the order of circulation is reversed immediately after birth, so the foramen ovale and ductus arteriosus are necessarily closed. Nevertheless, in a variety of cases, this foramen may for a long time be kept open from the right auricle towards the left, and in some cases even from the left auricle towards the right.

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325. I dare not profess to treat of the circulation of the spirituous fluid, and of the circulation of the white or purer blood antecedently to the appearance of the red blood; because



there are no facts to throw light upon these subjects, for at this early period of existence, all the parts are so white and translucent, that by no artifice is the eye enabled to approach them. This primitive age is consecrated to as it were perpetual ignorance and deep oblivion; and could we haply form any true conjecture respecting it, still no mind is endued with so divine a genius, as to stand as pledge and voucher in the case; and this, principally because the sense of sight is unable to supply the slightest confirmation. Hence the circulation which precedes that of the red blood, and which would appear to be a subject rather to be passed over in silence, than to be obscured by words, can be disengaged from its difficulties only after the circulation of the red blood itself has been shewn—a circulation which is cognizable by the sense of sight. Experience appears to prove, that the primitive corculum beats before the red liquor touches its threshold. “*The 1st day having passed,*” says Malpighi, “. . . a portion of the heart became visible, [projecting beyond the carina in the form of a hook.] . . . *After 30 hours,* . . . the heart was clearly discernible” (n. 243). Again he says: “It seems clear that the ichor, or matter above alluded to, which afterwards becomes red, exists antecedently to the motion of the heart; but that the heart, as well as its motion, are antecedent to the rubefaction of the blood (n. 242). *After 38 hours,* . . . a pulse was observable, and when this pulse ceased, a kind of dark line was at last traced. . . . The umbilical vessels were seen ramifying about in the circumference; . . . but their production as far as the heart was not yet visible.” (*Ibid.*) The corculum then is traversed by the white blood before the red blood, and by the spirituous fluid before either; its tissue, like that of every other viscus of the embryonic body, being formed out of the fibres of the latter fluid. Hence the circulation of the spirituous fluid is the most universal (n. 150—154). But it may be advisable before proceeding further, to recur to the circuits performed by the red blood, which are not so concealed from observation, being clearly indicated by the red color of the fluid; and then after treating of the red circulation, to add something on the subject of the white circulation, or that of the purer blood, and finally, on the circulation of the spirituous fluid.

326. *From the anatomy of the chick in the incubated egg, it appears that the circulation of the red blood passes through three remarkable changes and vicissitudes.* For at the commencement of formation the blood cannot be driven into a gyration similar to that which it afterwards describes when the little body is formed; because all things come and grow successively: because the heart has first to be initiated into the laws of its motion under the auspices of the brains: and because it acts at first as a triple vesicle, not as a cone: and also because the sanguineous stream cannot be transmitted through the lungs until they are opened. The circulation then goes through three remarkable vicissitudes, the general fountains of motion being also three (n. 279): although I should say that it goes through many and infinite changes were I to reckon the intermediate and particular stages that form so many transition-links from one grand stage to another.

327. *The first, when the primitive heart or punctum saliens propels the blood received, through certain vessels upwards toward the brains.* “After 40 hours,” says Malpighi, . . . “the heart pulsated, receiving from the veins a rust-colored humor, and sometimes a humor of the color of sere vine-leaves. For the external border of the umbilical vessels was surrounded by a thick venous circle, which at its extremities . . . opened into the heart. . . . At first the motion of constriction observable by means of the humor driven through the veins, was evidently into the auricle; from this the expressed juice was propelled [through a narrowed tube] into the ample right ventricle, by the constriction of which it was again protruded into a continuous appendage, from which there was a direct passage into the aorta. The aorta sent upwards certain considerable branches to the head, and was continued downwards in the form of a trunk, which, after dividing, extended as far as the extremity of the carina” (n. 242). And Lancisi says: “*At the end of the 2nd day*, the rudiment of the heart is seen as a crooked, continuous, yet irregularly constricted and dilated vessel, which beginning from the junction of the umbilical veins, or from the vena cava, is first dilated into an oval vesicle, . . . [and ultimately] opens into the continuous and proportionably narrow trunk of the great artery, which here and there divides into



various branches, but more particularly into two, which ultimately form the umbilical arteries. These terminate in a reticular plexus at the circumference of the cicatricula, and the umbilical veins there begin, and constitute an orbit of motion in the blood of the fœtus, running from the circumference through the veins to the præcordia, and from the præcordia through the arteries to the circumference" (n. 245). But this subject can hardly be understood by a bare description: if we examine Malpighi's plates representing the process of formation and the gyre of the first circulation of the blood, it will be seen to the life, that at this period certain branches proceeding from the last cardiac vesicle, convey the blood into a certain arterial sinus not unlike the sinus of the porta, and which sinus being inflected above the head, and then stretching down toward the inferior parts, is sundered into minute branches, and terminates in the so-called umbilical vessels. Not a trace of the descending aorta is yet seen; if there be any trace it is too slight to be visible.

328. *And the brains express it downwards into the umbilical vessels*, or into the border, area, or reticular plexus, where the blood in a manner disappears, but soon shews itself in the veins, by means of which it again arrives at the heart. This first and most simple circulation, therefore, is uniform, proceeding from the heart upwards and then downwards. In this epoch of the circulation we have to notice, 1. That the arteries into which the little heart now propels its blood, do not decrease in diameter, like the arteries that are formed in the body, but ultimately terminate in a certain large hollow or sinus, situated high up, or above the head. 2. That the blood is detruded from this channel or trunk into the smaller vessels, and finally into the smallest. "*At the end of 3 days*," says Malpighi, "... the blood received by the auricle from the vein, was propelled through a duct into the right ventricle, and thence into the left ventricle, and at length into the arteries, from which it passed into the trunk. From this trunk proceeded the umbilical branches, which terminated in twigs at the border, forming a reticular plexus" (n. 243). 3. That in this border or periphery the blood in a manner disappears, and then reappearing in the veins, flows back again into the heart. It would thus seem that this [arterial] trunk of the head is at one extremity, the area

of the umbilical vessels at the other, and the heart in the middle ; all within the sphere of the brain's activity.

329. *At this period the brains are the principal cause of the circulation of the blood*, but not the heart, as is evident from the mere description. For, 1. The [arterial] trunk of the head, immediately receives in a full stream the blood ejected from the heart or corculum ; and by its constriction and expansion, which probably arise from the animation of the living point, of the vesicles surrounding the brains, and of the zones, protrudes it still farther. 2. Since the trunk of the head is at one extremity, and the area of the umbilical vessels at the other, it seems that this area is within the sphere of the same animation that is the cause by which the blood is driven through the veins towards the heart. 3. The heart then, thus placed in the middle, exercises no other action than to receive the arriving blood, and to throw it out when received ; all other matters being under the auspices and government of the brains. 4. The heart is thus initiated into its future office ; and afterwards, when it has acquired a certain degree of strength, it is taken into consort, to minister in a subservient way in the formation of the body.

330. *The second change takes place when the aorta is extended downwards to the region of the abdomen.* While the first circulation of the blood continues, there is no appearance, as we above said, of the descending aorta, which is at any rate too faint to be noticeable. “*At the end of 2 days and 14 hours,*” says Malpighi, “... certain blood-vessels came from the heart, and passing towards the middle of the abdomen, produced the umbilical arteries and veins. . . . The blood was discharged into the auricle partly from the extreme border, and from the ascending and descending vein ; the auricle then, by its pulse, protruded it into the [right] ventricle, . . . and this, into the next ventricle, by which it was sent at last into the aorta, to be by it distributed to the head, to the surface of the body, and to the umbilicus” (n. 242). As soon therefore as the descending aorta is opened by the red blood, another gyre of circulation begins ; for the brains have summoned the heart into fellowship in forming the rest of the body ; which is done with this view—that wherever the brains and spinal marrow send the fibres and their pure fluid, there also the heart may send the vessels and the



blood: nevertheless the heart is so far kept in subservience to the brains, that it sends its emissaries to no other place, at no other time, and in no other quantity, than the brains direct. Thus the whole and the parts grow in mutual concord. This circulation appears to be of the following nature:

331. *The blood is then carried away by the inferior vena cava, after traversing the cardiac vesicles, toward the brains; and thence it is carried down by the superior vena cava, after again traversing the cardiac vesicles, through the descending aorta into the abdominal region; from which it returns through the inferior vena cava as before.* After a consideration of the facts presented by Malpighi and Lancisi, it cannot be advanced as certain, that all the blood that is carried from the heart to the brains, descends from the brains through the superior cava, inasmuch as it appears that a considerable portion of it is immediately derived into the border and peripheries, in order to ascend through the inferior cava. Be this as it may, before the first circulation can be changed into the second, there must it seems be this intermediary process; namely, one part of the blood descending from the brains must be carried into the peripheries; another part must be carried toward the heart, as a centre, to which indeed all the blood returns on completing its circulation: in the meantime, the vena cava ascendens and descendens are provided, as well as the aorta, which carries the blood both upward and downward. The heart is in the umbilical region, from which it maintains a relation to the superior and inferior regions; so that being located in the midst, it contains within itself the law of the consequents, and likewise refers itself to the antecedents, on which it is dependent (n. 252). This may be inferred from Malpighi's description just alluded to. As long therefore as the heart is not yet formed of united parts, but is only simply distinguished into vesicles, it seems to be undergoing an initiation into the mode of circulation which it afterwards retains till the period of birth; as we shall see in the sequel.

332. From the experience of Malpighi, it is very clear, that even before the union of the heart into its conical figure, the circulation is such as we have described. Thus he says: "The mystery of nature, on which I before touched, was clearly resolved in the course of this [the 3rd] day: the auricle receiving

the blood from the veins, pulsated with a kind of double motion, as though distinguished into two chambers, and thus the blood was propelled into the heart in a peculiar way, which requires further investigation" (n. 242). That a similar circulation continues afterwards, or when the cardiac vesicles are waiting in readiness to coalesce, as also after they have combined into a single conical heart, our author further again confirms in the following words: "*On the completion of the 6th day, . . . the heart, hidden within [the body], . . . had two pulsating ventricles, from which depended the sinewy auricles, of enlarged dimensions and exerting a double motion, and also the colorless vessels*" (n. 242). Again he says: "*At the end of the 7th day, . . . the heart, shut up within the thorax, . . . was composed of two ventricles, as it were contiguous sacculi, united together at their upper part, and with the body of the auricles placed upon the top of them; and there were two successive motions in the ventricles, and the same number in the auricles.*" (*Ibid.*) The mystery of nature, which Malpighi says is in want of further investigation, is plainly revealed, if we well examine the gyre of the second circulation (n. 331), and diligently compare it with that of the first circulation (n. 327). For if the blood, after receiving its determination from the brains, be conveyed into the little heart through the superior cava, nearly the whole of what is thus conveyed is sent down into the descending aorta and the inferior regions of the body; but all that arrives through the inferior cava, after passing the heart, is pumped up in the direction of the brains. And since this is done in a continuous stream, or successively, it follows, that the auricle and ventricle pulsate with a double motion; the auricle pulsates, for instance, first when the blood enters it from the superior cava, and again when the blood enters it from the inferior cava. The ventricle pulsates in consequence of its connection with the auricle; firstly, therefore, when the blood is driven into the descending aorta, and secondly, when it is driven into the ascending aorta; according to the author's description.

333. This successive circulation then, being performed by the heart, it becomes us to inquire into the mode by which it is effected, in order that we may see that a circulation of the kind is practicable; for at first sight it would appear, as if the blood,



after having traversed the simple vesicles, was carried upwards and downwards at the same time. That the case however is otherwise, is clear from a comparison of this circulation with the first. For there is a certain sinus or channel extended above the head (n. 328, 329), which receives the blood as soon as it is ejected from the heart, and drives it downwards into the peripheries and umbilical vessels, because at that period the brains are the principal cause of the circulation (n. 329). This being granted, or at least assumed, it follows, that the blood which rises through the vena cava, after passing the heart, is all conveyed toward the beforementioned arterial sinus of the head, which is then in a state of expansion. But when this sinus is constricted, and the blood is sent from it into the umbilical vessels, it then propels the blood it has received through the superior cava, into the heart, at which time the blood which has passed through the heart, cannot be driven toward the sinus, inasmuch as the latter is constricted or closed, but the blood is all sent toward the descending aorta, and so on. Thus while this sinus protrudes the blood once, the heart performs the same operation twice, which produces two successive motions in the auricles and two in the ventricles. Lancisi seems to confirm the fact of this mode of circulation, when he describes it in these words: "Moreover, it is worthy of remark, that as soon as the motion of the corculum begins, certain fine purpurascent lines (which prove to be the umbilical vessels) are traced from the border, or from the circumference of the colliquamentum in this situation, (as we said above,) to the centre of the cicatricula, where they terminate, and becoming enlarged form those vesicles, which are alternately filled, elevated and reddened by the influent blood; in other words, undergo diastole," &c. (n. 245). The reality of this first circulation is thus confirmed, as well as of that which comes to be described in the conified heart, before the lungs respire. On this subject we shall not dwell any longer, because there are but few ascertained facts from which we can speak. Meanwhile, from what has been said, we may perceive the reason of the wonderful contortion of the cardiac vesicles, before they unite into a single heart of a conical form: also why the foramen ovale opens into the two auricles, and the pulmonary artery communicates through the ductus

arteriosus with the aorta : which would by no means have been the case, had not such a circulation preëxisted. I would now merely add the proposition which follows in the series of the induction, namely, that *the circle which the blood thus describes, is as it were double, and reflex, but yet continuous. So long as this circulation continues, two motions must exist successively in the auricles, and two in the ventricles.*

334. *The mode and determination of the circulation in the united or conical heart, before the lungs begin to respire, is similar to the above.* The heart does not assume the conical form before the seventh or eighth day, or before the lungs make their appearance. “*On the 5th day of incubation,*” says Lancisi, “one may without difficulty see that the right ventricle of the heart has approached to the left, and is lying upon it, so that the two no longer appear separated, but conjoined and folded ; and much more evidently so on the following days, when all the segments of the corculum are packed into one mass, and twisted together in their respective places so as to form a single cone” (n. 245). And Malpighi observes, that “*after the 8th day of incubation, . . . lungs of a white color were seen to have sprung up beside it [the heart]. . . . After the 12th day, . . . the structure of the lungs was discernible, the little ribs were solidified, and the muscles spread over them externally*” (n. 242). As I have already remarked, Malpighi states that at this period similar motions are observable in the heart, namely, two in the auricles and two in the ventricles (n. 242).

335. *Thus the blood carried down from the brains through the superior vena cava into the right ventricle, is propelled therefrom through the ductus arteriosus into the descending aorta, and so into all the provinces of the inferior region. Then it ascends through the inferior vena cava, and is driven through the foramen ovale into the left ventricle, and from thence towards the brains ; and so on continually.* Or that all the blood of the inferior cava, or rather of the body, after passing the heart, is carried upwards to the brains ; and that all the blood of the superior cava, or rather of the brains and spinal marrow, is carried downwards to the body. (The blood also of the subclavians runs down into the superior cava, which seems to be the reason why the germ of the wings, as Malpighi relates, begins to appear in general



about the time of the first circulation.) So that there is not a drop of blood but returns before this circuit is performed. Munnicks is of the same opinion where he says: "Thus the blood that comes through the ascending vena cava from the lower parts, passes through the foramen ovale into the pulmonary vein, and all enters the left cavity of the heart. But the blood that comes through the descending vena cava from the upper parts, is all sent into the right ventricle" (n. 320). Verheyen evidently thinks that a certain portion of the blood of the inferior cava passes into the right ventricle; for he says: "What the actual quantity is [that passes through the foramen ovale into the left ventricle], I believe it to be impossible to determine" (n. 316). If merely for the sake of the argument we suppose the existence of such a circulation, it is clear that we must also suppose and conceive the existence of a successive motion, or that the blood flows from the superior cava into the right ventricle before it flows from the inferior cava through the foramen ovale into the left ventricle; so that the circulation may be compared with the figure 8; the superior circumflexion of this figure representing the superior circle of the blood, or that which passes through the brains and the two medullæ; while the inferior circumflexion represents the circuit that passes through the body: the conified heart being the concurrence or internode of the two circles. The circle is not however so uniform as is represented in the figure 8, because the blood describes its figure in accordance with the members placed in the circle. Nevertheless the comparison may serve to illustrate the continuity of its fluxion. Moreover since the current that describes and continues this double circle goes on perpetually, it follows, that it is present in the superior cava, or enters into the right ventricle, before it is present in the inferior cava, or flows into the left ventricle; consequently that there are two motions in the auricles and two in the ventricles, as Malpighi has stated. I ought to add, that it does not follow from this, that one ventricle expels its blood before the other, although the blood flows into them alternately; for as soon as one is filled so is the other, at least but very little after; thus each concurs in simultaneously expelling the blood. For the muscular series in the heart are not only particular and proper to each ventricle, but are also

common to both ; for which reason the blood cannot be expelled except by the aid and coöperation of the common muscles. This, I suppose, is what Lancisi means where he says: "The motions of the auricles, which as I before said are observed to be alternate with those of the ventricles on the first days of incubation, appear to be successive rather than alternate after the heart has attained its conical form" (n. 245). That there is such a motion and pulse of the heart, and such a circulation of the blood, in the unborn foetus, no one can doubt ; nevertheless it is the business of the intellect to ascertain whether this circulation coincide with the figure of the primitive conical heart, and whether it be the only mode of circulation that can be conveniently performed, and hence is necessarily performed, so long as a passage is kept open through the foramen ovale and ductus arteriosus. We are to bear in mind before hand, that such a circulation of the blood, and such a pulse of the conical heart, exactly coincide with the circulation and pulse of the vesicular heart before it is rolled into a cone (n. 330—333). That it coincides also with the first and most simple circulation (n. 327—329), which cannot produce any other than this continuous and composite circulation. That also from no other can a third circulation be formed, combining a simultaneous influxion of blood from both the superior and inferior cava (n. 345).

336. That all the blood of the superior vena cava flows into the right ventricle, is in some measure manifest from the continuity of that vein with the ventricle ; for the ventricle is so immediately subjacent to the vein as obviously to receive the stream that comes from it ; shewing that there is a continuation of the same stream into it as it were into its large recipient bed. From this ventricle there is no outlet but what leads into the pulmonary artery, and from the pulmonary artery, when the lungs are shut or constricted, into the ductus arteriosus, which according to the descriptions is of sufficient magnitude to receive and transmit the entire stream. The whole of the blood, then, that is transmitted through this tube, cannot possibly be conveyed to the carotids, and through them to the brains ; for the ductus arteriosus anastomoses with the aorta below the origin of the carotids. This is an anatomical fact recorded by several authors, and among the rest, by Morgagni, who says that this



arterial tube "is carried into the beginning of the descending aorta after that vessel has given off all its branches to the superior regions" (n. 322). No one therefore can doubt that all the blood of the right ventricle is conveyed to the inferior regions of the body through the medium of this tube, by which as by a bridge the pulmonary artery is connected with the descending aorta.

337. Anatomy further shews, that all the blood of the inferior cava flows through the foramen ovale into the left ventricle; for this foramen opens just at the entrance of that vein into the right auricle and ventricle so as directly to intercept its stream; the aperture is also of sufficient diameter to absorb and transmit the whole current. "The foramen," says Verheyen, "is situated between the inferior vena cava and the pulmonary vein; opening into the former immediately below a tubercle that lies adjacent to the first division of the vena cava; and into the pulmonary vein near the left ventricle. . . . It is so large at first towards the vena cava as to exceed the aorta itself in size, but where it terminates in the pulmonary vein it is somewhat narrower. In the upper part, towards the right ventricle, it has a raised border to prevent the blood from easily passing it by; but at the lower part it is comparatively flat and even, to make the entrance of the blood more easy" (n. 316).

338. The whole of the blood that is conveyed from the inferior cava through the foramen into the left ventricle, is carried away from this ventricle towards the brains and superior parts. (It is at the same time conveyed also from the brains to the spinal marrow, and through the subclavian and axillary arteries to the arms; although all the blood returns from the brain through the jugular veins, from the spinal marrow through the vena azygos, and from the arms through the subclavian veins, into the superior vena cava.) It is not however conveyed to the inferior parts or to the body, as is obvious if we attend to the rule given in n. 228, namely, that an artery in pressing its blood onwards, straitens itself and almost closes in relation to the antecedent parts of the vessel, in order to push the volume downwards. Thus the stream expelled through the arterial tube into the descending aorta, cannot be mixed with the stream expelled at the same moment from the left ventricle into the superior part of the aorta; for as soon as the blood rushes

out, which it does in a strong current, through the arterial tube, the upper part of the aorta, which is between the tube and the carotids, is closed, so that the two currents cannot mix, but each pursues its own path. Moreover the carotid is placed at the top of the arch, from which the aorta begins to descend; so that the passage from the aorta forms a declivity to the carotid, and is continuous with it; especially since the intermediate space is closed, and since the brains themselves, moving synchronously with the heart, eagerly snatch and draw up their blood (n. 348, 349). Verheyen intimates a similar circumstance where he says: "Since the descending aorta is much occupied by the blood conveyed through the ductus arteriosus, it is evident that it cannot receive much blood from the left ventricle, and therefore that nearly the whole, or at least by far the greater portion of the blood of this ventricle, is distributed through the superior parts of the body" (n. 316).

339. It only remains for us to explain, how the blood of the inferior cava can be all transmitted through the foramen ovale, without mixing with the blood of the superior cava, yet so as to allow a small portion, according to Verheyen (n. 316), to find its way into the right ventricle; or how the superior cava can distinctly carry its stream into the right ventricle, and the inferior cava distinctly carry its stream through the foramen ovale into the left ventricle; for it might seem as if nothing could prevent the stream of one vein from mixing to a certain extent with the stream of the other: as indeed is the case in the conical heart after birth, and particularly when the foramen ovale is closed, and the blood flows from the right auricle into the right ventricle, at the same moment that it flows from the left auricle into the left ventricle: a motion which is compound and simultaneous, while the former, of which we have been treating, is respectively successive and simple. Let us see therefore, I say, in what manner the blood may be thus transmitted; nay, that it can be transmitted in no other manner than the one we have mentioned, if we grant the existence of a successive motion. In the human subject, there is a septum situated between the two *venæ cavæ*; and in brutes a tubercle likewise. This division is somewhat prominent in the heart even after birth; but before birth, when the blood flows in from the superior before it



flows in from the inferior cava, the septum is produced as far as the border of the entrance to the right ventricle, so as altogether to intercept the communication between the blood of the superior and that of the inferior cava at the moment of their influx. For the blood of the superior cava presses upon this septum, but not that of the inferior cava, because the latter does not act then, but afterwards in succession; so that upon one giving way, the other acts upon the intermediate septum more effectually. Besides we learn from observation, that while the auricle and ventricle are in the state of diastole and impletion, they assume a comparatively oblong form. Thus Lancisi says: "Every time the whole quadricave muscle of the heart is strained and constricted, the auricles are seen to be depressed toward the base, and to descend; and the ventricles to be elevated toward the base and to ascend; so that the body of the heart, which before was oblong, becomes nearly round and spherical." (*De Motu Cordis*, &c., lib. i., prop. 37.) And Harvey says, speaking of the systole of the heart after birth, that during this motion, "the heart is erected and rises up in a point, striking against the breast, and causing a pulsation that may be felt externally:" moreover, that "it contracts all round, but more especially toward the sides, . . . a fact which is well seen in small fish that have conoid or elongated hearts." (*Exercitatio Anatomica de Motu Cordis*, cap. ii.) Now if this action of the heart be compared with its action before birth, it will be evident, that the intermediate septum is also elongated so as to take away all communion between the two currents, that no blood may at that moment escape from the inferior cava into the right ventricle. Add to this, that the foramen on the side next to the vena cava, when the blood yields, is not opened, and at the side next to the right and left auricle, is so drawn and contracted as to lose its oval figure, and assume that of a chink or line. That the blood of the inferior cava then yields, is proved by the reticulated valve of Eustachius; of which Heister says: "Eustachius does not call it a valve, but 'a membrane of wonderful construction, placed before the mouth of the vena cava ascending from the liver, just where it begins to merge in the right auricle, occupying its anterior half, and forming a kind of reticulation.' . . . Lancisi thinks . . . that this valve prevents the

blood descending from the jugulars through the superior cava, from encountering too violently the blood ascending through the inferior cava. But Winslow . . . shews that it not only has the use that Lancisi assigns to it, but especially in the foetus at birth, . . . serves to prevent the blood from flowing back from the right auricle or superior vena cava into the inferior vena cava" (n. 120). Thus every arrangement conspires to the production of this effect, namely, that the blood of the inferior cava may easily give place to that of the superior, and that the blood of one cava may not be mixed with that of the other, and that afterwards, when the inferior cava acts, its blood may not rush into the right ventricle, when already full and when the valves are closed; nor again into the superior cava, there being a fence interposed, which seems to be pushed aside in consequence of the stream of the inferior cava giving place to that of the superior. But the case is otherwise when the superior cava begins to act simultaneously with the inferior, as it does after birth, for then the intermediate fence is raised up on both sides, and thus the one stream is no longer intercepted and separated from the other.

Therefore during the period of this second circulation, the heart still acts under the auspices of the brains, so that as soon as the brains send down their blood through the jugular veins, the heart is bound to act, and to receive the advancing stream, although not at the same moment in which it receives that which comes from the body, and which as yet no muscles expel into the inferior cava: &c. But these observations are inductions from one or two experiences only; we require a more extensive and well ascertained series of facts before we can decide upon a subject of such vast importance. Thus then the two circulations are concordant, namely, the first and the last with the intermediate, and thus we have explained the proposition that follows next in the series of our induction,—*the heart itself distinctly determining the stream in both cases. This is the purpose of the foramen ovale and ductus arteriosus, without which such a circulation could not be carried on.*

340. *Thus before the blood is allowed to travel through the lungs from the right ventricle to the left, it is all sent to the brains previously to being conveyed to the body and its viscera. So that*



it may almost be said, that the brains then perform the office of the lungs, for as is generally known, all the blood afterwards passes through the lungs. The reasons appear to be, 1. That nothing may be formed in the body except under the auspices of the brains; so that the fibre shall not be able to act against the blood, nor the blood against the fibre; nor consequently the body, in any respect, against the determination of the formative force: these being the only conditions on which the whole and the parts can grow in mutual concord. 2. That the brains may instal and as it were initiate their primitive curriculum into all its functions, lest afterwards, when it is left to itself and the blood, discord should prevail between the vessels and the fibres. 3. That the brains may require and derive to themselves from the mother's store, or from the apparatus of the egg, all things that can possibly conduce to the work of formation and growth; for the brains have the prerogative of drawing up and demanding the proper quantity and quality of blood (n. 348, 349). The point of first importance is, that the fibres be provided with spirituous fluid; for the fibres do all the public and private business of the body, and there is really nothing alive in the body but the spirituous fluid in its own fibre and in the blood.

341. *And lest the brains should be contaminated by foul blood, it is first passed through the liver, to undergo purification.* Numberless facts tend to shew that the liver is the laboratory for the purification of the blood,—facts observed both in infants and adults, to say nothing of embryos. In adults, all the hard, old and obsolete blood, and the corresponding serum, appear to be sent away to the liver (n. 99). For the vessels that run to the liver arise in the region where the blood must purify itself from mixed heterogeneous and impure substances; for example, from the cœliac artery, which gives off the hepatic, and in a measure also from the phrenic arteries. In this region again we find the emulgents, which lead to the kidneys, and deposit the urinous serum in the bladder (n. 206). Other vessels again running to the liver originate from the mesenteric arteries, and hence from the intestines, large and small,—a sewer out of which they cannot come clean. Moreover the blood conveyed to the liver shews its spurious and contaminated nature; for it

is of a dark color, and differs from the genuine blood almost as much as that which sinks to the bottom of a cup when drawn, differs from the blood that floats at the top. The lymph too, in the lymphatics of the liver, is yellower than common, and bitter to the taste; a sign that the outcast blood is beset with fixed, alkalized and barren salts; giving to the viscus itself a disagreeable darkness. Its two secretions also, as well by their color and taste, as by their chemical properties, shew the impurity of their origin; for when distilled, they yield a large quantity of phlegm and volatile salt, as also oily particles united with fixed salts and earthy matter, and a substance which is easily converted into calculus and grit. Hence the quantity of this excrementitious substance increases whenever the blood is clogged with numerous oily and sulphurous particles (n. 98, 99). Its "quality is also impure in proportion as the blood labors under any serious disease." (Reverhorst,\* *Diss. de Motu Bilis Circulari*, &c., § 49.) It is also deposited in the duodenum and intestines, in order that such excrementitious substance may be voided by this passage, just as the urine is voided by another and proximate passage. For this reason the alvine excretions are tinged with a bilious and hepatic color in proportion to the quantity of the impurities supplied. But this does not prevent both kinds of bile, particularly the bile of the liver, from being of very considerable use before their ejection; for a bitter, pungent, irritating, purging, styptic, emetic substance of this nature, is required by the intestines in order to goad them to motion, and in order that the food that has passed through the pylorus from the stomach, and been macerated, extracted, and inspissated, may be duly operated upon by the requisite menstrua taken from the blood. For the chylopoietic menstrua follow each other in an orderly succession, according as the food is deprived of its better juices; as for instance, the saliva, the liquor of the œsophagus, the gastric juice, the pancreatic juice, the bile of the liver, which is poured forth continually, and the juice of the gall-bladder, which is poured forth only as occasion requires, and which if supplied at other times, or in a larger quantity,

\* Swedenborg refers to Nuck, but this appears to be a mistake. Reverhorst's Dissertation was printed at the end of Nuck's *Adenographia Curiosa*, &c., Lugd. Bat., 1696.—(Tr.)



than is requisite, vitiates the blood. All these humors are but species of one and the same genus.

342. Therefore such viscus, purificatory of the blood, is provided in the embryo and fœtus simultaneously with conception and growth; indeed it is innate in the fœtal body itself; and the maternal blood, when infected by any disease of body or mind, is carried directly thither through the umbilical vessels, before it is transmitted to the heart and the brains. In fœtuses, therefore, the liver is larger in proportion than it usually is after birth; as also is the sinus and vena portæ; the liver is likewise of a darker color, and the blood that passes through the umbilical vessels into the left hypochondrium, is redder and brighter than the blood returned thence through the ductus venosus into the vena cava. Hence we find so considerable a portion of meconium, or fœtal fæces, collected principally in the large intestines, and which cannot come from any other source than the liver, the pori bilarii, and the gall-bladder; not to mention the glutinous liquor that is found in the stomach. This order of things prevails principally in viviparous animals, which are nourished by supplies of maternal blood. The case is otherwise in oviparous animals, which at once enter upon and find in the albumen itself a choice, rich and perfectly arranged store; hence in them it is not till the 7th or 8th day, namely, when the body begins to draw food from both the yolk and the atmosphere, that the parenchyma of the liver is seen to grow from the offsets of the umbilical vessels; and this, in the manner stated by Harvey, “as grapes grow from the stalk of the bunch, as the buds of trees from the twigs, or as the young ears of corn grow from the blade.” (*De Generatione Animalium Exercit. xix.*)

343. While on the subject of the liver, I may perhaps be allowed, from the phenomena it presents, to confirm a part of what I have stated theoretically in certain preceding articles, in regard to the modes of performing the secretions. For according to Boerhaave: “there is in the liver a very singular circumduction of the blood; in fact, nothing like it has hitherto been found elsewhere in the body.” (*Inst. Med.*, n. 350.) I wish to confirm, I. what was stated in n. 225, namely, that in extracting solely from the blood and its serum so many and even more numerous humors, animal nature seems to proceed only by one

course, or to adopt only one method ; namely, at every circulation she rejects to the parietes or peripheries of its canal or artery the substances less adapted to fluency, while it contains the blood, with other homogeneous and apter elements, in the median or axillary line.—According to the statement of many anatomists, and in the words of Boerhaave, “In these places [*i.e.* at the minute ends of the vena portæ and hepatic veins] there is everywhere and always a little canal, arising imperceptibly from the acini of the liver ; accompanying each branch individually of the vena portæ ; enveloped in the same sheath with it, and firmly and almost inseparably adhering to that sheath ; gradually enlarging by the confluence of similar pipes ; and finally terminating at the trunk of the vena portæ in one considerable pipe, termed the hepatic duct, or the porus biliaris, by which a humor very different from the blood is constantly received, and discharged under the name of the hepatic bile.” (*Inst. Med.*, n. 343.) Thus there is no heavy, inert, angular, heterogeneous substance rejected from the axis to the circumference of the artery, but is derived into the biliary duct ; and there is no light, active, homogeneous substance, but pursues the axillary course as far as the little veins ; the vein being always a continuation of the canal of the artery. II. I wish to confirm what was stated in n. 226, namely, that so large is the number of the genera and species of secretions meeting together from foreign sources, even in any one single gland, vesicle, or cell, composed of vessels of a threefold order, or of the red and pellucid blood-vessels and fibres, that even this is sufficient for supplying the first principles for the concoction of any liquor.—For, according to Boerhaave, “Nowhere in the body do so many viscera, vessels, humors, and causes concur, to produce any fluid, as in the liver, to produce the bile.” (*Ibid.* n. 350.) And again he says, “In the liver there are simple glands ; lobules are formed of these glands ; lobes of these lobules ; and the liver of these lobes ; as proved by the examination of insects, fishes, quadrupeds, birds ; by the first appearance and early stages of the liver in these subjects ; by diseases, injections, and indeed by common eyesight.” (*Ibid.*, n. 342.) Were we then to enumerate the varieties of secretions in the vessels, cells, vesicles and glands of all degrees, the secretions flowing from



their own vessels and from other different vessels, having a different sort of blood; were we in addition to enumerate the mixtures of these secretions, we should find the number of species to be infinite, or at least to be one containing innumerable particular species. III. I wish to confirm what was stated in n. 226, namely, that the fluids which are thus mixed, are again conducted through filters, and after being percolated and discriminated in different ways, are again united, till finally they are formed into some tincture, essence, spirit, menstruum, laudanum, extract, or other recondite substance which the animal polity requires for the supply of its necessities, uses, or contingent emergencies.—For each individual vein that runs by the side of a biliary pore, sucks in and reabsorbs the matters that are more suited to the blood and less suited to the bile; as do also the lymphatics, which drink their portion and pour it back again, according to Nuck<sup>x</sup>: thus these substances are reunited again and again. Neither is anything drawn off into the cava by its five large and innumerable small branches but what is homogeneous to the blood; those matters that are homogeneous to the bile, and heterogeneous to the blood, being left behind. The secretions are united likewise even in the gall-bladder, if not by the biliary pores, except at the exit through the ductus cholidochus, yet by arteries of a not dissimilar origin, and in certain brutes by the hepatico-cystic passages. They are likewise reunited after the circuit made by the blood of the body, as by the mesenteric veins, the lacteals, and the vena cava. IV. Again I wish to confirm the position stated in n. 205, namely, that such things only are imported to, and allocated at, the little mouths and lips of the minute veins, as are to be seized and swallowed; consequently that there is a cause operating from a different quarter in producing such an apposition of aliments, antecedently to any choice exercised by the veins.—We shall say nothing of the various modes of apposition and conveyance in the biliary pores, in which those things are reabsorbed that are not suited to the bile; for before the mind is illustrated and confirmed by what is palpable we cannot argue from what is impalpable. But it is manifest to the senses, that the biliary pores themselves continually pour the bile of the liver into the duodenum, as the intestines, pancreas, stomach, œso-

phagus, palate, gums and tongue, pour the several humors that are proper to them ; and all these being mixed with the extracts of the food, are placed in apposition with the lacteals and mesenteric veins, with the mesenterics at least in birds. That the cause of this apposition precedes, and arises from a different source, is very evident from the causes of the discharge of bile, which are either external or internal (n. 216). The *external* are those of the stomach and intestines, as when they are either too much relaxed or too much irritated ; moreover the discharge takes place according to the quantity or quality of the food, or of whatever else may be received into the system ; for the gall duct joins the biliary duct at an acute angle ; the common duct descending obliquely, and applied to the duodenum at acute angles, penetrates its outer coat, and after perforating it, runs for some distance between the coats before opening into the intestines. This shews that it is not always, or under all circumstances, that the bile can be poured from the liver, but only when the intestines are relaxed. Thus the external causes of the discharge of bile, arise from the state of the intestines ; as indeed may be clearly inferred from the hepatic plexus, which is connected with the stomachic plexus. The *internal* causes of the discharge of bile, are the affections of the brain when acting very strongly on the fibres of the body, as in anger, choler and sadness. V. I will also confirm the position of n. 227, that there is a certain equation of quantity and quality of the fluids, pervading the system, and to which nature, as if for the sake of equilibrium, tends and aspires with all her might. For when more of one species of liquid is demanded, consumed, or eliminated, in one extreme than in another, a new liquid of the kind must immediately run thither to supply the want, from all parts, corners and provinces of the kingdom, near and remote.—This is very manifest in the liver, where the two biles (the hepatic and the cystic) considerably increase in quantity according to necessary or contingent use ; as in those persons whose stomach and intestines lose their natural tension, and in choleric and melancholy subjects, who are frequently afflicted with jaundice and other diseases, arising from black bile, and whose intestines, whether owing to external or internal causes, require a large quantity of bile, in place of which a new supply imme-



diately succeeds, and this process sometimes goes on to such an extent as to contaminate the whole sanguineous system. All this is with a view to the establishment of that natural equilibrium which is to be produced by an equation in the quantity and quality of the liquids. For this reason a number of passages are prepared, which lead to this organ, and which are adapted to make the afflux of bile correspond with the efflux. Thus it is that use or habit becomes nature (n. 227). These remarks, however, are intended only as cursory: the subject will be more fully treated when we come to speak of the Liver and other similar organs.\*

344. *But these things take place with a difference in oviparous and viviparous animals respectively.* The difference arises from the circumstance, that viviparous animals are furnished with their beneficent store in the mother and her blood; while oviparous animals derive theirs from a provision of appropriate matters most methodically coördinated in the egg. Hence viviparous animals are provided with a placenta, fitting the folds, pores and open vessels of the uterus; and on the other hand oviparous animals have waving superficies, zones and vesicles, by means of which the chosen food is emulged in the order in which it lies prepared and laid up in the egg. In viviparous animals, therefore, first the most spirituous blood, then the more simple blood, and lastly the red blood, are respectively conveyed, in order to be purified, first through the root of the ovum, then during its descent through the Fallopian tubes, everywhere by virtue of the pores and the viscid substance of the seed there collected; then through the uterine placenta, and the umbilical vessels whose roots are there, to the liver. The case is different in oviparous animals, in which the liver does not appear till the 6th or 7th day; for all things contained in the egg are pure, and are called into activity by the simple heat of brooding, while in the womb the materials are often contaminated, namely, by the emotions and heats of the animal and rational mind of the mother. Hence in viviparous animals the blood has as it were a different gyre; for being attracted through the umbilical vessels alone, the form of its gyration is changed. Still however the circulation, considered in itself, seems to be

\* See the *Animal Kingdom*, Part I., *passim*.—(Tr)

threefold; for there is the primitive circulation, as in the egg before the existence of the heart, and which is perhaps from the liver to the brains; there is another in like manner to the head, after first passing the heart; and there is the circulation that takes place when the heart acts as a cone or as a united body. Thus the difference of circulation is a difference only in form, which does not prevent the circulation being the same in kind. But these remarks are only hypothetical, and must necessarily partake of this character in proportion as experience does not go hand in hand with inductive reason.

345. *The third change occurs after birth and exclusion. For the blood is then driven from the superior vena cava and from the inferior vena cava simultaneously, into the right auricle and ventricle, and traversing the lungs, into the left auricle and ventricle, and thence into the trunk of the aorta.* This circulation of the blood, and the pulse of the heart thence arising, are treated of throughout in Chapter VII., as is also the following lemma: That “*at this time there are no longer two successive motions in the auricles and two in the ventricles.*” Let us proceed therefore to another part of the subject.

346. *From which the brains take out and attract no more blood than their state demands.* For after birth they are roused, if I may use the expression, to the exercise of thinking, perceiving, knowing, and willing; they are awakened as from a deep sleep; for which reason they do not at this period admit all the blood of the heart or the body; but in their place substitute the lungs, through which they transmit the whole of it: the brains meanwhile exercising an elective power, and merely summoning such a quantity and quality of blood as their state requires; a larger quantity when the cerebrum is affected and intoxicated with anger, rage, pride of self-esteem, &c.; and a smaller, when it is cast down from hope, or benumbed by failing confidence, or cold fear; states in which the animal mind falls flat like a peacock’s plume. Moreover, the brains regulate the quantity of the quality; for instance, when the cerebrum is intimately busied with cares or reasons, and deeply exercises its organic forces and faculties, and causes its animal mind to outlie the bodily senses and to marry the rational mind. The case is otherwise when the cerebrum has no



object before it, and lies loose and lazy in whole and in part, and avoids doing anything to excite the sleepy mind. In short, the brains, according to use, invite blood of a better or worse character; and in the former case, they in a manner banish the hurtful and material blood far from the threshold and sacred shrine of their inner organs.

347. But perhaps I may be thought to speak without due regard to physics, when I say, that the brains draw up the blood, or borrow from the heart or body such portion of it as their state requires, inasmuch as this would appear to imply that they exercise a species of attraction. Hence, although this subject does not properly belong to the present Part, yet as, in case I were silent, I might be supposed to have committed an error in regard to the most essential laws of nature, I am under the necessity of briefly explaining my position. In n. 217, it is shewn, that the arteries of the brain completely emancipate themselves from the heart and blood of the body; the internal carotid, by perpetual contortions and inflections, continued from the first threshold of the cranium to the base of the brain, as also by divesting itself of its muscular coat. The *vertebral artery* likewise emancipates itself by the same expedient as the internal carotid, as is clear from the following description; to wit, that as soon as it gains the support of the vertebræ, it enters the foramen in the transverse processes of the cervical vertebræ, and giving off branches on every side to the spinal marrow and its integuments, and the neighboring muscles, it climbs by a steep acclivity to the superior condyles, where it makes two turns and then a third; first, round the second of the cervical vertebræ called the epistrophæus, then back again round the first vertebra or atlas, and then outwards in a large lunar arch, from which it immediately returns. Thus after sending branches to the occiput, and to the occipital and cervical arteries, it enters the great occipital foramen, where the first pair of vertebral nerves, or the last pair of nerves of the head, passes out, and where the spinal accessory nerve enters. Being then provided with a coat from the dura mater, it inflects itself within the cranium, describing a short circle, toward the posterior part of the medulla oblongata, and unites on both sides to form a little trunk, which is called the posterior spinal artery. The anterior

branch of this artery first returns directly from the basilar or sphenoidal apophysis of the occiput, then after a slight oblique ascent meets its fellow approaching from the opposite side, and both combine into a common trunk, (almost at the first step of its progress from the cerebellum), which trunk is then called the cervical or basilar artery. From the point of coalition, or from each crus, springs the anterior spinal artery. Thus it appears that not only the internal carotid, but also the vertebral, and with these the anterior and posterior spinal arteries, entirely release themselves from all continuity with the heart and its undulations; and this the more evidently, because as soon as they enter the cranium, they become enlarged, and do not, like the arteries of the body, diminish and continually spread into ramifications, until the carotid artery has first reached the cerebrum, and the vertebral artery the tuber annulare, as their motory organs (n. 192. 5). It now only remains for me to explain the manner in which these arteries, emancipated from the control of the heart, and subjected to that of the brains, dispense their blood, and procure it in accordance with their state, without being compelled to receive it uninvited.

348. All these arteries and veins, as well as the sinuses, are so placed in the stream of the cerebral motions, as not to allow themselves to be expanded or constricted by any other motory force than that of the animation of the brains. The large or superior sinus of the falx is attached to the hemispheres of the brain, by the fibres, lacerti, vessels, prolongations of the pia mater, and by the muscular points that Pacchioni calls glandular congeries, that is to say, where they are present, or the necessity of the case requires their assistance. This sinus is attached also to the hemispheres of the brain by what are denominated the chords of Willis, which so regulate and restore its natural mode of tension and expansion, as not to allow it to be opened and closed by any other motory force than that of the brain acting from both sides upon the dura mater and the falx, or upon the membranes that invest the sinus. This is plainly admitted by Ridley, who says that the action of this sinus is derived from the motion of the brain alone. (*Anatomy of the Brain*, Chapter VI.) In like manner the lateral sinuses are attached to the hemispheres of the brain, for at their first outset



and grand anastomosis many strong and sinewy productions, and motive fibres and aponeuroses, are apparent. In like manner again we find the fourth sinus attached to the cerebral hemispheres, and so lying between the cerebrum and cerebellum, that when either of them expands, and particularly the cerebellum, the sinus is compressed and contracted like a press, and is afterwards opened and expanded by the inward receding of the brains. The same remark applies to the smaller, both longitudinal and lateral sinuses, when they are present. The case is somewhat different with the four shorter or longer sinuses of the sella equina; of which we shall speak in the sequel. All the sinuses are so secured to the hemispheres of the brains by fibres analogous to those of muscle or nerve, and by vessels and sinews that act as straps, that they necessarily perform their systaltic motions in accordance with the animatory motion of the brains. This will be found explained at some length in the Part on the Sinuses of the Brain. Moreover, the vertebral artery itself, and particularly the united artery termed the cervical, where it traverses the semi-orbicular protuberance of the medulla oblongata in the channel excavated for it, is placed under similar fetters, so as to expand and contract according to the alternate and mill-like motion of that protuberance. The same remark applies to the anterior and posterior spinal arteries; to the vertebral sinus; and to the veins in the spinal marrow. It applies likewise to the carotid artery, and to every one of its branches and twigs; for this artery is larger between the lobes, smaller between the serpentine prominences, and smallest between the little furrows and ridges. In this respect it is not unlike the larger, or longitudinal and lateral sinuses between the hemispheres, whence its branches may be called arterial sinuses or sinuli; and they are subtended by the pia mater, as the great longitudinal sinus is subtended by the dura mater when passing into the falciform process. None of these arteries can be expanded or constricted except according as the brain, with its lobes, prominences, and ridges, opens and shuts. They are consequently so enclosed in, and annexed to, the brain by most minute fibres, by prolongations of the membranes, and by vessels, that they are opened when the brain collapses, and constricted when the brain expands. This is

effected by an external force, by means of the vessels insinuated into the cortical substance of the brain, and their fibrils binding all these tunics in such a manner, that in proportion as they are laterally expanded they are at the same time longitudinally contracted, or shortened ; so that in proportion as the canal is laterally drawn apart, it is longitudinally relaxed. I shall not mention the other arteries and veins within the brain, as those in its ventricles, ducts and crannies, all which are so situated in the stream of the motion of the brain and ventricles, &c., as to be expanded and constricted in unison with each other. Hence there is nothing more palpable than the nature of the motion of the brain and its members,—nothing more clear than the particular use of each part and the general use of all.

349. Let us now return to the consideration of the mode in which the brain obtains its blood, or, according to our theorem, subtracts the quantity which its state requires. If the arteries, veins and sinuses of the brain are opened by its animatory motion, it follows that a fresh supply of blood must then flow into them, and this by continuity from the carotid artery and its tortuous channel in the cavernous receptacles, and into this channel, by continuity, from the ventricose and circumflex cisterns of this artery which precede it, consequently from the external carotid, and thence from the aorta and the heart ; this is the reason that the carotid arises as a branch from the aorta. The case is the same as if we took a bladder or siphon full of water, and immersed one end of it in a vessel of water ; for if we then dilated its walls or its external surface, especially if in so doing we shortened the length of the siphon, fresh water would flow into the vacuum thus created, as we find from experiment. Now this is the result of the tendency to natural equation (n. 227), by means of which, according to mere physical laws, nature aspires to her equilibrium, with a view to avoid a vacuum, in which she perishes or is nothing. Such then is the mode in which the brains act and fill their arteries, and it may well be denominated *physical attraction* ; not that it is attraction in the proper sense of the term, but an impletion of vessels by the drawing of their tunics farther apart and then closer together, or causing them to exercise a species of suction, such as we see displayed in pumps and syringes.



A similar mode of physical attraction prevails in every part of the body, as for instance in the muscles ; from which, no sooner is the blood forcibly ejected, than they immediately aim at the re-impletion of their vessels. It prevails more especially in the brains of embryos, which emulge and milk out the maternal blood by a mode of suction. It prevails in the chick, which in the incubated egg attracts all the nutritive juice from the albumen, by the animation of the zones and vesicles. It prevails also in the primitive corculum during its initiation into motion, the blood being pumped from the heart into a certain large sinus of the head. It prevails finally in numerous other instances, where it so escapes our notice, that we are led to regard it as the result of some occult quality, or of some cause or other of which we are ignorant. I would here add, that from a survey of the vessels of the brains, it is evident, that during the constriction of the arteries, veins and sinuses of the brain, (which takes place simultaneously with that of all its other cavities, such as its ventricles, convolutions, ducts, crannies, &c.,) there is no passage open from the arteries into the veins, nor from the veins into the sinuses, but only into the cortical and cineritious substance, and from one sinus into another, or from the falciform and fourth sinus, into the lateral sinuses, hence into the jugular veins, and *vice versâ*. When these things are demonstrated, for they are effected by wonderful expedients, it will be evident that the drawing open of the vessels is not violent, but almost spontaneous ; for the blood from within co-operates with this motion, being compressed against the parietes of the vessels, and thus aiding them when they come to be expanded. These remarks are the mere natural consequences of the numerous facts ascertained by experiment, and with which I might fill my pages were they not devoted to a different subject.

350. The law that obtains with regard to the quality of the blood, is similar to that which obtains with regard to its quantity ; as for instance, that the brains do not procure, and subtract for their use, blood of any other quality than such as their peculiarity of state demands. For as often as they require a supply of blood of a superior essence, which they expend either upon their fibrils, or upon the interstices between either the fibrils or the fascicles ; in a word, upon the nerves of the body ;

then, for the sake of preserving the natural equation of the fluids, a fresh supply of blood of a similar kind flows from the blood of the body in the place of that which is expended, according as the state of the brains requires. For nature everywhere strives to be perfectly similar to herself (n. 227). This follows by consequence, since the blood is not brought into the brains by the heart of the body, but by innumerable corcula in the brains (n. 177): for were the blood forced by the heart into the brains, they would have no power to select such a portion as was suitable to their state in regard to quantity and quality. But in order that such a power may be conceded to them, all their blood is invited through the medium of the physical attraction I have mentioned. Enough, however, has now been said on this part of the subject.

351. *Thus, as the order of circulation is reversed immediately after birth, so the foramen ovale and ductus arteriosus are necessarily closed.* “After birth,” says Lower, “and when respiration begins, the foramen ovale and arterial canal . . . gradually and daily diminish, until at length the former is quite closed, and the latter degenerates into an impervious ligament” (n. 317). Munnicks observes that “the foramen ovale is closed by no other means than by its valve, which in point of substance, tenuity and translucency, always retains its original valvular character” (n. 320). With respect then to the *foramen ovale*, it must necessarily be closed by degrees after the order of the circulation is inverted, or when the influx from the venæ cavæ into the auricles and ventricles of the heart is no longer successive but simultaneous. For the influx from the venæ cavæ is rendered simultaneous immediately after birth, for which reason the velum or intervening septum is elevated (n. 339), and the two sanguineous streams are intermixed. The expansions of the auricles are also no longer successive and alternate as before (n. 335), but simultaneous; for the blood flows from the now opened and traversed lungs, into the right auricle, in the same moment in which it flows into the left auricle; and thus the blood reacts from the left auricle as much as it acts from the right. The closure of the foramen is the more effectually insured by the circumstance, that the valve hangs downward on the side of the pulmonary vein, and being fixed to its post to



ward off the fluid, is also depressed when it is compressed. This change likewise indicates, that the former circulation was successive, and that it is followed by one that is simultaneous.

352. The arterial tube now abandoned at both extremities, is constricted, and the lungs inspiring spontaneously, take up the blood. This constriction is the consequence of the order of the circulation being changed, and all the blood which before passed through the brains (n. 340) now passing through the lungs; and it is occasioned not only by the pulmonary artery, but also by the aorta, which are joined to each other by this tube. First it is occasioned partly by the pulmonary artery, because, as we before said, the lungs inspiring spontaneously, forestall its reception of the blood. It is well known that the blood flows freely through the lungs when expanded, but not when collapsed; in evidence of which it will be sufficient to recite the statement of Fantoni. "Scarcely any blood," says he, "passes through the lungs during their continued state of collapse. Meanwhile, if air be thrown in through the trachea, all the operations of the parts will be beautifully restored; the veins, the auricle, the heart, and the artery, will be seen to be emptied, and the lungs to be partly released from the old blood, and partly filled with new" (n. 323). But it may be asked, how the lungs, by the simple entrance of air, take up the blood with so much avidity as to occasion the abandonment of the former unobstructed passage through the arterial tube?

353. This arises not only from there being a larger quantity of blood now forced into the pulmonary artery, for the blood both of the superior and inferior cava now flows into the right ventricle, but also from the circumstance of the little pulmonary arteries themselves being so disposed round the vesicles that are in continuity with the bronchial vessels, that while these vesicles swell with air, the little arteries are elevated to their natural situation, and are at the same time opened; not unlike what I have stated in respect to the arteries of the brain (n. 348, 349), but in an inverse order, so that when the lungs are expanded the arteries also are expanded, but when the brain is expanded, its arteries are constricted. But the manner in which the arteries are disposed in the lungs, must be reserved for the special

treatise on those organs.\* I would here only premise, that the lungs collapse in virtue of an effort of their own, but are expanded in virtue of the force of the entering air, which exercises a pressure in proportion to the height of its column. Consequently in producing expiration there is no need of any external and constricting muscle in the thorax, but only in producing inspiration; neither in this case is there need of any other muscle than merely the one which opens the thorax, the air alone effecting all the rest. All these functions are performed accordantly with the influx of the nervous fibres. *Without the lungs*, the twelve dorsal or intercostal nerves act upon the muscles that open the thorax, and have no antagonists, at the same moments that the spinal marrow is moved systaltically, and the lungs themselves synchronously (n. 283). *Within the lungs*, little nerves enter from the two pneumonic plexuses, and from the great cardiac plexus (see Chapter VII.): the nerves from the great pneumonic plexus enter the vesicles that are in continuity with the bronchii; the nerves from the smaller pneumonic plexus enter the pulmonary arteries, as well as the bronchial: the nerves from the great cardiac plexus enter all those arteries that come off from the pulmonary artery proceeding from the right ventricle of the heart. Thus while the bronchia are expanded by the air, the fibres of the great pneumonic plexus are put on the stretch, and are in a perpetual effort to constrict the vesicles; for which reason the lungs spontaneously collapse, and the air is expelled. But the fibres that are extended from the great cardiac plexus, let go the arteries that are continued from the large pulmonary artery proceeding from the right ventricle of the heart through the lungs, at the same moment in which the aorta and left auricle, and consequently the large pulmonary artery, are expanded; all of which takes place at one and the same time. Hence it follows, that all these pulmonary arteries are in the state of expansion when the left auricle and the aorta are in the state of dilatation; that is to say, when the systole and diastole of each auricle and artery, viz., the aorta and the pulmonary artery, become simultaneous, as is the case after birth. Such appears to be the

\* See the *Animal Kingdom*, Part II. Chap. IV.—(Tr.)



reason why the lungs take up the blood with so much avidity after the order of circulation has been changed and the arterial tube abandoned.

354. But at the other extremity of this tube, or where it communicates with the aorta, there is likewise a cause for its closure. For as soon as little or no blood flows through the tube from the pulmonary artery into the aorta, the communication between the carotids or the arteries of the head, and the descending aorta, or the arteries of the body, is no longer intercepted (according to n. 338); for the effect ceases when the cause ceases. Hence we see the principal reason why the brains no longer draw up all the blood of the left ventricle, in that they do not require a larger quantity than the peculiarity of their state demands (n. 346—350). Hence also in the arch of the aorta, from which the carotid artery branches, a larger quantity of blood remains than usual, and which as the heart urges it on, cannot move in any other direction than down the descending aorta, into which therefore it is determined, the course which it is left to pursue being now not toward the brain but into the provinces of the body. For the muscles of the body now require a larger quantity of blood than before, and being excited into act, drive it into the veins, whence a fresh supply comes from the same source, that is, from the top of the aorta (n. 227, 234). As soon therefore as the infant is born into the exercise of its muscles, or of those members that are excited to act by a certain natural instinct, such as the stomach, intestines, kidneys, liver, pancreas and spleen; or again of those members that are exercised by a previous effort of the will, and hence deliberately; then, from that moment, the blood is determined from the heart and aorta into the places where the quantity thus ejected is again required (n. 227). A similar operation takes place here to that we observed with regard to the foramen ovale (n. 351); that is to say, the blood reacts from one side upon the tube in the same proportion in which it acts from the other side, producing an equilibration, and consequently the want of a preponderating force to drive the blood through the tube. The arterial tube being thus abandoned on both sides, and having no longer any office to perform, collapses into a ligament and tendon, much like the umbilical vessels and an infinite number

of others in the body, in the brains, their membranes, meninges and muscles, which at one time were pervious to the blood, and which are now cords, or sinewy, tendinous, cartilaginous and bony fibres, or others of nondescript character.

355. *Nevertheless, in a variety of cases, this foramen may for a long time be kept open from the right auricle towards the left.* “We have very frequently seen,” says Morgagni, “that the part of the valve which extended beyond the anterior and inferior margin of the foramen ovale in the fœtus, even in old subjects was not only not united to the wall of the pulmonary vein, but presented the appearance of two or more unequal sacculi, or oftener still, of one large sacculus; . . . the orifice of which sometimes looked downwards, and frequently forwards; and admitted a large probe, and even the end of the handle of a scalpel, between it and the wall of the vein, to . . . a [considerable] depth. . . . At the very bottom of the sacculus, between it and the front and upper border of the foramen ovale, I have frequently seen a minute passage still open for the blood, and once of such a kind as to admit the point of the handle of a scalpel without any difficulty into the vena cava. This passage I found in a female subject, and the like once also in that of a male at least forty years old” (n. 322). I observed in n. 351, that when the order of circulation is inverted, the foramen ovale must of necessity be gradually closed, because the blood reacts from the left auricle as much as it acts from the right, since the quantity flowing through the lungs into the left auricle is similar to that which flows in from the venæ cavæ into the right. The closure of the foramen ovale, therefore, depends on the equation and equilibrium existing between the sanguineous stream in the left auricle, and that in the right. Thus whatever cause tends to disturb or destroy this equation, produces its effect in this first and last place of ingress of the blood, that is to say, in the heart. For in every one of the three circulations above recounted, an equilibrium of the flowing blood is designed and provided. It is not therefore surprising, that when the order of circulation is inverted (n. 351, &c.), the current cannot be immediately equilibrated, and that the short channel of the foramen ovale is for some time kept open, as in infants. The causes which operate in so long keeping the foramen ovale



open from the right auricle to the left, or more properly into the pulmonary vein, and hence directly into the left ventricle, are the following ; too small a bulk and capacity in the newly-formed lungs ; such a state of the lungs as does not admit of their eagerly taking up and transmitting the blood ; feeble respiration, or such as is impeded after birth by a variety of causes, as suffocation in the mouth or nostrils, too great a constriction of the breast by wrappages and swathings ; obstruction of the glottis, trachea, bronchia, and of the pulmonary arteries and veins : sternutation not supervening after birth, neither yawning, coughing, crying, which are all so many incitements and means resulting from a blind instinct to divert the blood or change the circulation in new-born infants ; a deficient arousing of the brain, and a lurking species of primeval dormancy ; a want of due proportion between the capacity of the auricles and ventricles of the heart, so that should the former be larger, the latter are less than they ought to be ; the frequent occurrence of palpitation of the præcordia ; unexpected fright experienced by the infant, or pregnant mother ; connate timorousness, paleness and shivering arising from coldness : no back current of the blood into the veins, when the right auricle is constricted ; as for instance, from the superior cava into the subclavian, jugular and azygos veins ; debility of the arterial system ; debility of the muscles, so that when the blood is propelled from the left ventricle into the aorta, it runs on unrestrained into the veins ; in a word, the want of a due establishment and support of a general equilibrium of pressure ; also the various diseases arising from these causes, such as inflammation of the lungs, leipothymia, leipopsychia, syncope, apnœa, orthopnœa, insensibility or privation of the faculty of perceiving the action of objects, spasms, convulsions, ataxy or irregular motion of the spirits, &c. We even find that after the lapse of years, as in adult age, the foramen, though once closed, may again be opened by the application of force, and its valve be ruptured ; as in cases of palpitation, sudden and frantic terror, collapse of the lungs : it occurs likewise in those who, on having once to all appearance been dead, are recorded to have been again restored to life ; hence the valve may be found even in adults like two unequal sacs, or more frequently, according to the statements of Morgagni and the

observations of Verheyen and others, like a single large sac facing forwards, thus appearing as if it had been violently protruded; a circumstance which frequently occurs in the case of divers. For in the heart there is a confluence of all the blood, and it endeavors to equilibrate the waves thereof, and when its right auricle is too full, it is under the necessity of affording a vent for the current by keeping both passages open into the same ventricle, that is to say, one through the lungs, and another through the foramen ovale.

356. *And in some cases even from the left auricle towards the right.* According to Manget: "Littre asserts that he found the foramen ovale open in a man of forty, and this, in such a manner, as to allow a passage from the pulmonary vein to the vena cava, but not *vice versâ*; for the orifice of the foramen was thrice as large towards the pulmonary vein as towards the vena cava" (n. 321). Heister gives the following short statement of the discussions on this subject: "The use of the foramen ovale formerly gave rise to considerable discussion between Mery, (who maintained . . . that the blood flowed from the left auricle, through the foramen, into the right auricle,) and Duverney, Sauvage, Sylvester, Bussiere, Lister and Verheyen, who all upheld the contrary, and contended for the received opinion, which by the way is that generally maintained at present. On this subject the reader may consult the *Hist. de l'Acad. Roy. de Paris*, 1699, and other writings of the learned. It is to be observed, that in the *Hist. de l'Acad.*, 1717, Winslow seems in some measure to agree with Mery. . . . He has also advanced more on the same subject in the *Hist. de l'Acad. Roy.*, 1725." (*Comp. Anat.*, not. 38.) The foramen may be opened by causes opposite to those above recited. They must however be so extremely violent, as either to rupture the margin opposed to the blood and fixed to its post in the sinus of the left auricle, or to thrust it forward away from its natural situation and state into the other and opposite chamber; for the change in the natural order of things must indeed be great which shall occasion the veins to be filled by a current of the blood pertaining to the arteries. For when the arterial and muscular system are conjointly in a state of effort, if by any chance the passages into the veins are partially obstructed, then, unless the foramen were open when



the order of circulation is inverted, or the blood effected an exit along this passage, the infant would scarcely survive the crisis, as there would be vast danger of the smallest arteries being ruptured, or of the larger ones being stretched to a degree of aneurismal tension and laxation, or of a dilatation of the præcordia. We may see in Chapter VI., n. 431—444, that under the foregoing liabilities, an exit is afforded through the coronary vessels, through which, as through the foramen ovale, there is a passage from the right side of the heart to the left, and from the left to the right.

357. The causes therefore which operate in keeping open the foramen ovale are the following,—an undue constipation of blood in the left auricle, and a comparatively small supply in the right, arising from a too eager or insatiable appetency for blood on the part of the lungs; or from the capacity of the left ventricle of the heart not being proportioned to that of the right; or from such an obstinate resistance or constriction of the arteries that they do not admit the whole of the injected wave; or from the impeded or repressed egress of the wave into the veins, for which reason it is first driven into the smallest arterial vessels, so as to occasion great inflammation in the face, skin and viscera; or from a too energetic action of the general equilibrium of pressure (n. 178); or from the sudden and violent change occurring at birth in the previous order of the circulation. There are some cases also in which only a few fleshy ducts are found in the left ventricle; on which subject see Chapter VI., n. 443, 444.

358. We may here observe, that when this foramen is kept open, so as to preserve a passage from the left auricle to the right, it is a sign of the person being of the most robust make in his heart, arteries and muscles. Hence this phenomenon is to be found in those who from the first breath they draw, feel no connate pusillanimity or fear; consequently in persons of an undaunted frame, whose lungs never collapse for want of a due supply of blood, but their bosom swells, and their arterial blood, giving strength to the muscles, is restricted to the limits of its own vessels, and never deserts them in a spirit of fear (n. 231, 233, 234); who are gifted with a higher order and larger abundance of life (n. 231, 232). For some there are who are such by

birth ; who from the very womb, cradle, and swaddling clothes, breathe a spirit of valor, which ultimately in adult age becomes heroic. As indications of their character, we find them lustily pushing their way out of the womb into the atmosphere, as if their lofty spirits could no longer brook their confinement ; and the moment they come into contact with the air, they salute it with a vigorous sneeze. With a deep yawn, as if tired of infancy, they anticipate the period of their maturity ; with compressed fists they pugnaciously contend with their swathes, and rage and fume against any who would impose upon them even the semblance of restraint ; and already armed with teeth, they bite the teats of their mothers. But this class of men is rare, and consequently there are but few instances of the kind on record.

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359. Hitherto we have spoken of the circulation of the red blood, but before concluding this chapter, we will say a few words on *the circulation of the white or purer blood*, as it takes place both before and after birth in the embryo and chick. We stated above (n. 279), that the circulation of the purer blood is much promoted by the respiration of the lungs ; but since this blood, as noticed in the beforementioned article, is intermediate between the spirituous fluid and the red blood, therefore its motion depends on the motion of the brains as well as on the motion of the lungs. Had we therefore suppressed this part of the present chapter, the observations above advanced might have been rejected as pertaining to the obscure reveries or paradoxes propounded on the subject of occult qualities. But that we may proceed in due order, we shall inquire, 1. How the spirituous fluid, and its blood, called the purer or simpler blood, are derived from the brain, through the chemical organs and members of its laboratory, into the jugular veins, and thence into the right chambers of the heart. 2. How the blood is passed through the embryonic lungs before they have respired, and what circle it then performs. 3. What is the nature of the assistance offered by the lungs, by which the circulation of this blood is promoted after birth.



360. With regard to the first point, *how the spirituous fluid, and its blood, called the purer or simpler blood, are derived from the brain, through the chemical organs and members of its laboratory, into the jugular veins, and thence into the right chambers of the heart*,—we would here remind the reader, that the object of the present brief remarks is not to explain the manner in which the spirituous fluid is conceived and born in the cortical and cineritious substance of the brain; for this will be treated of in Parts IV. V. and VI. Neither is it the object here, to shew the manner in which this fluid is transmitted into the nerves, and through the nerves into the provinces of the body; for this is the office principally of the cerebellum and of the medulla oblongata and spinalis, and on this again I shall treat in the above Parts. But my present object is, to shew how the purer blood is derived from the brain itself (the preëminent gland of its kingdom, and a chemical laboratory perfect in all organic apparatus) into the jugular veins, and so into the right chambers of the heart. But this is a subject of such a nature, that we cannot explain it, without premising an anatomical description of the members of the brain, which shall serve as a clue to direct us in the labyrinth.

Whoever examines the anterior and posterior surfaces of the brain, beginning at the cortex, and following the medullary threads and strata, through the corpus callosum to the base of the fornix, and thence through its roots and columns into the anterior ventricles, where the whole medullary substance that is employed in carrying down the spirituous fluid has its termination near the choroid plexus;—whoever also examines the course of the spirituous fluid as conveyed from this plexus through the two foramina into the third ventricle, and so into the infundibulum, and from this into the pituitary gland, and by it into the receptacles of the sella equina, and at length into the sinuses at the base of the brain [*fundi*], and from these into the lateral sinuses and jugular veins; will discover a laboratory constructed with stupendous art, devoted to astonishing chemical operations, and replete with innumerable organs, bladders, coated phials, filters, and even baths. The use of every member and organ will represent itself, if we conceive and contemplate the machine as put in motion; if for instance we

consider that all the fibres (with the exception of those that are determined from the brain through the medulla oblongata into the medulla spinalis, and so into the nerves, and particularly into the last of the spinal nerves) are collected by astonishing flexures into the base of the fornix as into a central axis of the medullary substance, and from this are disseminated round as so many roots in each anterior ventricle, where they expire and exhale their spirituous fluid, which is immediately mixed, copulated and tempered with the liquid exuding from the choroid plexuses; if we consider again that this fluid is next conveyed into the third ventricle, through the two foramina, by means of the action and rolling of the corpora striata and thalami of the optic nerves in general, and of the testes, nates, and pineal gland in particular; that it is again expressed by means of the infundibulum toward the pituitary gland, where it is again in its passage strained, filtered and separated, so that only the purer essence may penetrate into the human pituitary gland, the rest being projected round the gland, which is moveable and expansible in the sella equina; whence it is distinctly determined by the alternate expansile action into the receptacles of the sella equina, and into the shorter and longer sinuses; and indeed the more spirituous essence, or that which has penetrated the interiors of the gland, is derived through small sinuses into the long basilar sinus, which is transverse and circular, into the superior or narrow sinus, even into the osseous substance itself, and hence into the tortuous belly and ampulla of the lateral sinuses; but that which follows the circuit of the gland, is expelled into the cavernous receptacles of the sella, and through the inferior basilar sinus, shorter or larger, into the fossæ jugulares, and so through the veins toward the vortex of the heart. Nor is there any difficulty arising from the smallness of the transverse and circular sinus, of the orifice of the longer sinus in the lateral sinus, or of the rostrum proceeding from the infundibulum and inserted into the pituitary gland; since all these passages mutually correspond to each other, to the volatility of the spirituous essence, and to its rapid flight through pores adapted to its nature and purity, as well as to the quantity of this essence expressed from the fibres of the brain which cross the base of the fornix. This, however, is but a



compendium of the subject ; when it is properly followed out it may afford matter for at least two or three distinct Parts.

361. Now as the sinuses of the sella equina are not attached to the falx and septum, and do not possess a lacertous texture, like the superior longitudinal and lateral sinuses, so they propel their liquid in a different manner (see above, n. 348) ; and besides this, they propagate it by a kind of slight expansion and constriction, and by the assistance likewise of modulation and modification ; for this spirituous fluid is highly elastic and modifiable (n. 100) ; hence it must be actuated conformably to its nature ; that is to say, by all species and degrees of modifications. Those sinuses, therefore, pass over the petrous portions of the temporal bones which are subject to perpetual sonorous vibrations ; for they inclose, and insulate, the very region that contains the labyrinth, vestibule, and cavity of the tympanum and ear, together with the inferior curvature of the lateral sinuses. Moreover, the superior and longer sinus that conveys the purest fluid, is itself carried over a highly tremulous area ; the shorter sinus, however, is extended into the neighboring parts, and to the junction between the temporal, sphenoid and occipital bones. The auditory nerve itself, or the nerve of the seventh pair, enters the foramen of the cranium, and the Fallopiian aqueduct or internal ear, almost in the middle of the island ; hence the whole of the tremor that pervades it, diffuses itself on every side at the moment of its entrance into the cranium ; especially since the fascicles of its harder portion are interpolated with the meninx, and the membrane of the tympanum communicates with the dura mater, and the dura mater with the thin substance of the sieve-like [*multifori*] cranium (n. 171). To this end a twig runs back from the auditory nerve through the foramen scooped out in the petrous bone, and spreads upon the dura mater. The Eustachian tube also extends to the same source, so as to convey down thither the whole tremor received from the larynx, while at the same time it is conveying it toward the ear. Nor would I omit to mention the eighth pair, which closely follows the jugular vein from the cranium, and at the same time sends back some of its stamina into the dura mater, and in the form of fascicles, accompanied with a meninx, perforates and lacerates the foramen, and then embraces and en-

folds the vein; to the aid of which nerve the recurrent comes afterward from the larynx and trachea. And not only the above sinuses, but also the incurvated and retorted part of the lateral sinuses, (which receives the spirituous treasure of the brain, and into which also all the rest of the blood of the brain is conveyed,) closes one side of the tremulous area, and approaches nearer to the receptacles. In like manner the second process of the dura mater sent down toward the receptacles, reaches the base, and immediately by continuity carries all the tremulous motion, received and collected from every periphery, into the cavities of the same sinuses. In order that this contremiscence may pass immediately into the liquids, all the blood of the lateral sinuses enters the osseous caverns, the interior lamina of which, is thin, and invested with the meninx, and reaches to the jugular veins, into which the shorter sinus insinuates itself through the osseous or membranous interstice; so that no tremor creeps along the surface and the petrous caverns, but passes through the hollows scooped out in these bones into the veins (n. 171). In order that it may be conveyed to this place by the liquids, a vein is brought hither from the internal ear, and another from the external, while at the same time the artery, which is the third branch belonging to the dura mater, arrives here through the same foramen. A large quantity also of the cortical substance overlaying these sinuses, together with a prolongation of the dura mater, which is concentrated nearly in this region, transmits its vibrations into every point of them. Moreover the beginning of the longer sinus passes over the trunk of the fifth pair, which is hard and at the same time soft,\* and then traverses and unites all the organs of sense, of hearing, taste, smell and sight; so that being actuated by the modifications of all these organs, it infuses them into the sinus. The sixth pair of nerves, also joining itself with the great intercostal nerve, and hence with the nerves of the whole body, traverses the bed of the inferior sinus, and communicates to it the tremulous state of the body itself. Now in order that the blood of the brain, thus tremulous, and leaping in tune from the cranium, may be properly commingled, the jugular

\* Qui durus et simul mollis.



vein attracts branches from the whole vibratory [*contremiscente*] tract; from the scutiform cartilage; from the trachea, to which it is attached; from the circles and membranes thereof, which are always put in a tremulous motion by the voice when speaking or singing; from the muscles themselves and the region of the external ear; from the temporal, occipital and sublingual region; from the region of the os hyoides, by means of which the larynx is associated with the tongue when speaking. And since the mastoid and scalene muscles, and the cervical vertebræ, participate in the vibration of the larynx, the jugular vein derives its streams from this quarter likewise. Thus all these are placed in the same stream of undulatory motion, granting that the animatory motions of the brains and lungs are synchronous.

Hence it follows, 1. That this tremulatory undulation consociates the homogeneous parts of the blood, and dispels the heterogeneous; in order that the blood may enter the ventricle and press of the heart in a more prepared and fluid state; and may commence the circulation. 2. That more especially the spirituous fluid may be impelled to union with the purer blood, in a way thus conformable to the state of the brains; and at the same time that it may be carried forward to its outlets by the expansion and constriction of the sinuses: and this, both by *external causes*, or by the modifications of the organs of the corporeal senses; and by *internal causes*, or by those proper to the brain itself while it is borne into modifications by the mere representation of images. 3. Thus we see what it is that external sensation, the affections of the animal mind, hilarity, gladness, laughter, &c., contribute to promote the circulation of this liquid; and how it is that sadness, anxiety, grief, and painful emotions, impede its course; inasmuch as the former open, and the latter close, the passages through the sinuses and cranial bones; for according to the experience of Willis, this fluid pursues its course from the pituitary gland through the manifold passages and pores of the cranium, into the lateral sinuses and jugular veins. (*Anatome Cerebri*, cap. xii.) 4. Thus, evidently by means of the trachea together with the brains, the lungs promote the descent of this blood, and the current of the first circulation, towards the heart.

362. *How the blood is passed through the embryonic lungs before they have respired, and what circle it then performs.* I say, that in the foetus, none of the red blood passes from the right ventricle to the lungs; but only the purer blood (n. 91—94, 136, 146). For the ductus arteriosus is sufficiently large to receive and transmit all the red blood of the superior cava and right ventricle (n. 336). Nevertheless there are those who doubt whether a portion of the blood is not transmitted from the pulmonary artery through the lungs themselves. Thus Lower says: “The blood expelled from the right ventricle is transmitted for the most part through this [arterial] canal into the aorta, and distributed with the rest of the blood throughout the body” (n. 317). And Verheyen says: “Although the pulmonary arteries after their division are collectively somewhat more capacious than the ductus arteriosus, it does not therefore follow that a less quantity of blood passes through the latter than through the pulmonary arteries; but rather a larger; for the transit of the blood through the lungs of the foetus is exceedingly difficult, inasmuch as they are collapsed by reason of having no respiration, and therefore considerably compress their blood-vessels (n. 316). Boerhaave has the following: “That portion [of blood] that has entered the right side of the heart, is all driven by its action into the trunk of the pulmonary artery, which experiences considerable resistance in the collapsed and heavy lungs of the foetus: hence the blood greatly dilates that part of the trunk that is free of the lungs, often making it larger than the aorta itself; and only a small portion of blood passes through the lungs. . . . All the blood therefore that is driven from the right side of the heart, passes from the pulmonary artery, through the ductus arteriosus, into the aorta; overcoming the resistance of the blood in the aorta more easily than the resistance of the collapsed lungs.” (*Inst. Med.*, n. 681.) Again he says: “When the lungs are distended with air, the arteries and veins are expanded, and offer less resistance to the blood driven from the right ventricle; the course of this blood into the veins is expedited, and the whole conveyed rapidly to the left ventricle. During inspiration the lungs are comparatively pale. When the lungs are collapsed, the pulmonary artery can scarcely be filled by the force of any liquid injection;



whereas when their air-vessels are inflated, the blood-vessels easily admit of impletion.” (*Ibid.*\* n. 200.) That the collapsed lungs prevent the passage of the red blood, is proved by the single experiment of Fantoni. “If the breast of a living dog be opened,” says he, “and the ribs forced outwards, the lung collapses, and no longer admits the air. . . . The heart still beats, but in vain attempts to throw the blood into the pulmonary artery, for the latter is contracted; and in vain undergoes relaxation in order to receive the pulmonary blood into the left auricle. Both the vena cava and the auricle, as well as the right ventricle and the pulmonary artery, are swollen with the obstructed blood” (n. 323). See also n. 352, 353.

363. Since then no portion of the red blood at this time traverses the lungs, it may be asked, whence do the lungs derive their blood? For agreeably to the experience of many anatomists, [and in the words of Munnicks,] “The lungs in the fœtus are comparatively red, and during the early period of formation very heavy and dense” (n. 320). In answer we observe, that there are the bronchial arteries, which arising in different ways, either from the aorta, or from the superior intercostal artery, or from other arteries, are so connected to the bronchia, and so accompany them to their termination, that no human industry can point out a single branch of the trachea, however minute, that is not supplied by their ramifications. They are associated by anastomoses in various places with the minute twigs of the pulmonary artery, with the intercostal arteries, and with those that come from the spinal marrow. They often transmit a branch to the azygos. See Ruysch and Winslow.† For after birth the bronchial arteries are in the stream of the motion of the lungs, and of the brains and medullæ, as well as of the heart. This is the reason of the variety of their anastomoses.

364. If then it be asked, what flows through the pulmonary vessels connected with the ventricles of the heart, I answer, it is only the purer blood, which is always prior to the red blood,

\* This latter citation does not occur in some of the early editions of the *Institutiones Medicæ*.—(*Tr.*)

† See the *Animal Kingdom*, vol. ii., n. 387, p. 126; n. 409, and notes, p. 199—202; where citations are adduced from Winslow and Ruysch.—(*Tr.*)

not only in the lungs, but also in the heart and every other viscus. This is confirmed by the varied experience of Malpighi; for instance, when he says of the pulsating vesicles constituting the heart, that they are surrounded (for he has more than once indistinctly seen it) "with muscular fleshy portions that have not yet taken on opacity or redness" (n. 242). Again when he says: "It seems clear that the ichor, or matter above alluded to, which afterwards becomes red, exists antecedently to the motion of the heart; but that the heart, as well as its motion, are antecedent to the rubefaction of the blood." (*Ibid.*) "A long interval . . . elapses, during which the heart and vessels are pervaded by an ichor, which at one time is yellow, then rust-colored, and at last blood-red" (n. 243). "After the 8th day of incubation, . . . lungs of a white color were seen to have sprung up beside it [the heart]" (n. 242). The case is the same in all the other viscera, and even in the arteries and veins themselves which are penetrated by a white fluor before they receive one that is colored and red. Nay, in the body itself, after formation or after birth, there is nothing more frequent than exsanguious vessels, which are nevertheless in continuity with blood-vessels, and are opened or inflamed immediately on the operation of any external or internal cause, as in the face, skin, membranes, muscles, and in all the viscera (n. 146). The same phenomenon is displayed by the Ruyschian process of injection, by means of which a larger number of vessels is frequently opened than is ever discernible in the living membrane; it is likewise displayed by the process of maceration adopted by the same author. A similar law obtains with regard to the lungs, where the red blood gathers [*excubat*] in the dilated pulmonary artery, and is diverted through the open passage of the ductus arteriosus into the aorta. Still, in the meantime, a more pure, volatile, light and elastic essence is elicited from the blood thus propelled (n. 100). For when different species of liquids are acted on by one and the same impulsive force, the more light and elastic move with the greatest celerity; as clearly proved by the phenomena of practical physics, and by the laws of the motion of elastic bodies. Thus by the impulsive action of the right ventricle, the purer blood precedes the red blood (n. 454), and penetrates the pores adapted to it, and consequently the



pulmonary arteries, which are as yet impervious to the red blood: these it permeates as far as the left ventricle, and together with the blood of the bronchial vessels (n. 363), adapts and makes straight the passages that the red blood is to traverse after birth.\*

365. Consequently this purer or white blood at this time describes a simple circle, namely, from the brain to the right ventricle; thence to the lungs, thence to the left sinus and ventricle, and thence again to the brains: thus it describes the same circle that the red blood first describes (n. 327—329). In fact, for the reasons given above (n. 338), the blood cannot in any quantity be pressed then into the descending aorta. The brains themselves likewise repeatedly demand all the better blood (n. 346—350). Thus also in the formation of the body, the purer blood is the second cause, while the red blood is the third cause (n. 272). The circulation of this purer blood is relatively simple, prior, and universal (n. 146, 148); for it not only arises from the cerebrum, and is derived through the jugular veins into the right side of the heart, but it is likewise derived from the cerebellum and from the two medullæ, and through the fibres immediately into every blood-vessel of the body; hence through the veins into the inferior cava, and by this way into the right side of the heart. This appears to be the cause of the phenomenon of which Malpighi speaks, where he says that “the blood propelled through the arteries [of the chick] was of a deep red color, but that which returned through the veins had a yellowish hue” (n. 242).

366. It now remains for us to consider *how the lungs contribute after birth to the circulation of the blood, and especially of the purer blood*, as alleged in n. 279. Here it is that we are preceded in some degree by the light of experimental knowledge; for the capillaments of the vessels that are penetrated with a blood not red but white, are opened for the reception of the red blood equally by the influx of the brains into the fibres, and by the expansion and contraction of the lungs. I say by the influx of the brains, as appears when the brains are affected with grief, indignation, anger, shame, &c.; for then the red

\* See the *Animal Kingdom*, n. 409.—(Tr.)

blood immediately forces its way into the texture of the capillary vessels, and suffuses the cheeks and other extremities with redness and fire. A similar result is produced by the general effort of the lungs, as in the case of wrestling, fighting, striving, parturition, expelling the fæces, shouting, and a thousand other instances. At this time the exsanguious vessels are likewise opened to the red blood. Under any of these circumstances the action of the brains, as well as of the lungs, upon these vessels, is manifested.

367. But before we can properly compare the action of the brains with that of the lungs, and infer that the lungs as well as the brains promote the circulation of this white blood, it is of importance to demonstrate, that the action of the lungs is equally universal with that of the brains, and that whatever part of the body is devoid of this action, ceases in a short time to be associated with the other parts. It would seem at first sight, as if the effect of respiration did not extend far beyond the thorax; but if we contemplate the several varieties of respiration, and reduce them to one common or general result, we shall perceive, that if the respiration does not always actually extend beyond the thorax, still it is in the effort to do so, or to be in action everywhere.

368. Respiration may be either ordinary or extraordinary, or asthmatic and morbid, or different according to the different disposition as well as action of the ribs, the vertebræ, the sternum, the neck, the abdomen, the brain, the cerebellum, the medulla oblongata and spinalis, the nerves and the muscles: respiration is one thing in women who wear tight stays, another thing in pregnant women; different again in infants, boys, adults, and old persons, respectively: respiration may be either pectoral, attended with rising of the chest; or dorsal, with adduction and extrusion of the vertebral column; or subthoracic and abdominal: it is different again in other states, for instance, while we are sleeping and snoring, from what it is while we are awake, standing upon the feet, bending forwards, backwards, or sideways, or lying upon the back, or upon the breast: it varies also respectively while we are laboring, shouting, speaking, singing, eating, crying, laughing, coughing, sighing, yawning, sneezing, running, panting, riding, fighting with the whole



chest, arms, or feet, sitting, ascending, descending, expelling the fæces, passing the urine; also during parturition, copulation, stretching the first thing in the morning: it changes with all the diseases of the body, with all the emotions of the animal mind, as in joy, grief, anxiety, anger, fury, fear, intrepidity, attention, eagerness. The varieties of this motion are so great that they seem contradictory to each other. Thus it is brought about with contraction of the chest and sternum, with expansion, with depression, with elevation; with a diversity of bendings of the vertebral column, and with the straightening out of the same; with an expansion of the abdomen, or even a drawing in of the same; with a yielding, or with a resistance, of the diaphragm: so that it is impossible to determine what muscle is about to operate upon the cavity of the thorax, unless the action be previously given or assumed. At one time there is a powerful action of the subclavius, serratus, pectoralis, trapezius, latissimus dorsi, and of many of the cervical and even lumbar muscles; at another time, of one or another of the abdominal muscles, or of the diaphragm and all of them at once; at another time again, of the vertebral, intercostal and sternal muscles. Nevertheless, all these muscles do no more than expand or constrict the chamber of the thorax in divers ways, either inferiorly, superiorly, anteriorly, posteriorly, or obliquely, in every possible direction. Nor do the intercostal muscles seem manifestly to elevate the ribs, unless they concur with other muscles external and more general. They are moreover destitute of antagonists, in order that they may comply with the general motion of the dorsal nerves; for which reason indeed they deserve properly speaking to be called inspiratory. All the other muscles, which have an equilibrium, are circumstanced differently when the spinal marrow and the brains act in a general manner; for then the antagonist of each muscle is acted on in the same degree as its fellow or companion.

To these remarks I may add, that four of the pairs of the cervical nerves in a wonderful manner correspond with each other, in opening or closing the thorax; for relatively to the muscles they influence, they form a reciprocal proportion, consisting of two ratios or four terms. Thus the first pair bears

the same relation to the second, as the third to the fourth ; for the first pair moves the posterior muscles of the neck, the second its anterior muscles ; the third the anterior muscles of the thorax, and the fourth its posterior muscles ; so that when the posterior part is bent backwards, the first pair concurs with the fourth ; when the breast is bent forwards and inwards, the second pair concurs with the third ; for it is a general rule, that the rectangle of the means is equal to the rectangle of the extremes ; or as in arithmetic, that the product of the means is equal to the product of the extremes. Hence, the action of the second and third being equal to the action of the first and fourth, we have an equality or equilibrium of actions. But to return :

369. From these remarks it appears, that there is no motion more universal and general than that of the lungs, and that they act on all points of the body, if not in a palpable manner, yet with a *conatus* towards it. They act on the muscles of the neck, occiput, *sinciput*, forehead, face, eyes, lips ; the action extends even to the muscles of the tibia and foot, as is clearly and sensibly perceived when the air is strongly inspired into the lungs, and for some time retained there. Any part of the body, therefore, that is devoid of this action, ceases in a short time to be connected with the rest ; and this, especially because the lungs by their expansion and constriction act on the most general nerves of the body ; namely, on the two sympathetic nerves, or the intercostal and the *par vagum*. These nerves, passing through the fleshy substance of the diaphragm, pervade all the viscera of the body, and penetrate all their arteries, veins, muscles and glands ; and while the lungs operate on these nerves by a common force, they exercise an action on all the points to which they penetrate. In Chap. VII., on the Motion of the Heart, it is shewn that each of these nerves arises from the medulla of the cerebellum, and that as they are acted on, so they act on the muscles, which they enter, according to the origins of the motions existing in the body. Hence it would follow, that the lungs by an external action on these nerves, carry on the same cause as the cerebellum carries on by an internal action through the fibres of the same nerves ; that hence the lungs act



on even the smallest blood-vessels, whose sanguineous circulation thus depends upon both the lungs and the brains; according to the proposition, and to the assertion in n. 279.

370. We will now, in the last place, add something upon the circulation of the spirituous fluid, as being the most universal of all (n. 38, 97, 148, 150, 151, 154, 325). There is nothing in this whole kingdom really substantial and alive, except the spirituous fluid in its fibre, or in the blood; or except the fibre and blood with this its fluid; all other things are only passives and accessories, by means of which the spirituous fluid is copulated to form fluids of another degree, and the fibres to form solids or continuous things of another degree. Therefore wherever this fluid is not present, neither is the brain present; neither is one part living in consort with another, or fulfilling the office of an intermediate, so as to refer itself to its antecedents, and at the same time to maintain a relation to its consequents (n. 252). Hence every part in the body is only so far in the series and circle of the relations of its kingdom, as it is connected with other parts by this fluid rightly determined. Thus the circulation of this fluid is the most universal, and neither the beginning nor the end of it can be determined; and through its mediation, everything in its own limited universe is continued, moistened, nourished, renovated, formed, actuated and vivified (n. 148, 154).

371. Besides these circles of fluxion in the blood, there is also a circle of perpetual formation, namely, of the red blood from the purer blood, and of the purer blood from the spirituous fluid. On this subject we have frequently spoken above. For in order that subsistence may be perpetual existence, the same circle must be perpetually continued in the subsisting body that had been in the existing body; hence the blood, in order to subsist, ought to be perpetually coming into existence; for which reason that which is formed, is always regarded as still to be formed, and that which is to be formed is regarded as already formed (n. 261, 262). This circle cannot exist and subsist without the circulations just described, and when these are performed, all things accord, and the system coheres.

## CHAPTER V.

### THE HEART OF THE TURTLE.

372. THE use of the foramen ovale and ductus arteriosus, is shewn by the heart of the turtle more clearly than by any other. For in this animal there are two large arteries, one of which resembles the ductus arteriosus; and two foramina, one of which resembles the foramen ovale of embryos, which foramina are opened and shut according as the animal is in the water or in the air. To make the subject clear, then, I will add a brief chapter on the heart of the turtle.

373. MORGAGNI. "In the presence of some scientific friends from Venice, we once dissected a turtle of 36 pounds weight. After completely separating the heart from the pericardium, (for it was connected with the lower portion of the latter, not by tendinous filaments, but immediately); and after carefully observing a number of nerves distributed particularly over the back of the heart, and after inspecting the auricles, and trying in vain to say which was the larger of the two, we proceeded to open the heart itself, and made the following observations. The venæ cavæ united their two channels in a large and almost entirely membranous sinus. This sinus communicated with the right auricle by a large and nearly circular orifice, furnished with two membranous valves possessing fleshy fibres. These valves, which were similar in their figure and mode of position to the lids of the eyes, were longer than the diameter of the beforementioned orifice, and were so placed under it, that when they contracted, they could close it altogether. From the right auricle there was a passage into the right ventricle, and from the left auricle into the left ventricle, and no valves were prefixed to either passage but those we are soon about to describe. Between the auricles there was a large, thin, membranous septum, but which, in its upper part, was furnished with fleshy fibres. From its lower part two thick fleshy valves hung forward into the right and left ventricle



respectively, and their inclination was such that it was easy to conjecture, that when the ventricles contracted, the valves must be raised by the compressed blood, and compelled to shut the auricles. Of these valves, that which hung forward into the right ventricle was the thickest and largest. Moreover, the great artery arose from the summit of the right ventricle, and soon after divided into a superior and inferior trunk. And from the same ventricle, but a little anteriorly, another considerable artery issued, which, after making a curve of about ten finger-breadths in length, terminated in the inferior trunk of the great artery. At the place where the two arteries arose from the heart, two semilunar valves were prefixed to them. But the left wall of the right ventricle was perforated by two foramina, one anterior, the other posterior. The anterior foramen, which was circular, and had no valves, was large enough to admit the point of the thumb; the posterior, which was as it were triangular, with the base of the triangle uppermost, was larger than the anterior; but was covered superiorly, for about one third of its extent, by the two valves that hung forward, as we before said, from the septum of the auricles into the ventricles: the other two thirds being covered by a most delicate network of glistening white fibrils, which nevertheless transmitted the blood through their meshes. By this foramen the right ventricle communicated with the left; by the other, it communicated with a certain third ventricle, which was situated in front, between the right and left ventricles. This intermediate ventricle, small as it was, reached nearly from the top to the bottom of the heart, and at the base of the heart gave off the pulmonary artery, the commencement of which had in like manner two semilunar valves. The pulmonary veins opened into the left auricle, and this, into the left ventricle; no valves (as we could well perceive) being placed either at the ends of these veins, or at the orifice of this ventricle; except indeed the one which we have mentioned as hanging from the septum of the auricles. With respect to the thickness of the ventricles, I remember that the left had thicker walls than the right, and the right, than the anterior part of the intermediate ventricle. The length of the bundle into which the arterial trunks were closely collected above the base of the heart, and the diameter of the several vessels, are points which I do not well remember. But I perfectly recollect, that there was no orifice through which the left ventricle could send its blood, except the posterior foramen, and none through which the intermediate ventricle could receive its blood, except the anterior foramen; through which two foramina, as I have stated, each of these ventricles communicate respectively with the right ventricle. Such being the case, it was easy to see, with regard to the blood returning from the body, and to that

returning from the lungs, that the former was sent through the right auricle immediately, the latter, through the left auricle and the subjacent left ventricle ; and that it was all driven finally into the right ventricle, to be propelled by the latter, and by the communicating intermediate ventricle, into the body universally, as well as into the lungs. It was easy to see, therefore, that the left ventricle was as it were a second auricle added to the right, and the intermediate ventricle an [auricular] appendage of the right ; and that the right was in fact the same as what we generally meet with in fishes as a single ventricle : although in the turtle, enlarged by a manifold comminuting as well as propelling mechanism to promote the circulation of the blood. In the turtle, I say, for although in the land tortoise I thought I saw a communication between the ventricles, and in the fresh-water tortoise three ventricles disposed as in the turtle, yet on account of the small size of their hearts, and of the slight nature of my observations on the point, (for I had other objects in view at the time,) I am not able at present to affirm it as certain. But to return to the turtle,—although I have without difficulty ascertained that the blood is driven from the left ventricle through the posterior foramen into the right, yet I do not clearly understand as a parallel what blood can be transmitted from the left auricle of the foetus through the foramen ovale to the right. For the foramen ovale has its valve on the side next to the left auricle ; and this valve is capable of entirely closing it ; and when the auricle contracts, the valve cannot be lifted upwards from the foramen by the action of the blood driven downwards.” (*Advers. Anat.* v., *Anim.* 17.)



#### INDUCTION.

374. FROM a comparison of the heart of the turtle possessing three ventricles, with the heart of land animals, which possess only two, the difference between the cases is evident. Thus, 1. The heart with three ventricles sends out two large arteries from its right ventricle; while the heart with two ventricles sends out only one large artery or aorta, and this from its left ventricle. 2. The former sends out the pulmonary artery from the intermediate or third ventricle, so that this ventricle appears to be an extension of the canal of the pulmonary artery; while the latter sends out the same artery from its right ventricle. 3. The former sends out no artery from its left ventricle, which would seem to be only a sinus for the reception of the pulmonary venous blood; but the latter sends out the aorta immediately from its left ventricle. 4. Hence in the former case the two posterior ventricles ought to communicate with the right common ventricle through two foramina, the septum being accordingly perforated; but in the latter case, or in the heart with two ventricles, this ought not to obtain. 5. In the former case, there is a certain venous sinus placed before the right auricle, from which the united sanguineous current is driven into the auricle, through certain valves which are suspended over it, to prevent the blood from flowing back again. In the latter, or in the heart with two ventricles, there is an influx of blood distinctly and immediately from the inferior cava, and again from the superior cava, neither is there any valve to prevent the reflux. Let us now proceed to the heads of the induction, which are as follow.

375. *The turtle possesses a heart with three ventricles, in order that as an amphibious animal it may live either in the water*

*or the air.* We find the proof of this fact in natural history. For the same reason the turtle has lungs, and the pulmonary artery is sent to a single and peculiar ventricle. This is done in order that the artery, together with the lungs, may be closed when the animal is under water, and opened when it is in the atmosphere, without giving rise by these vicissitudes in its mode of life, to any confusion, or any general change in the circulation of the blood, such as would otherwise inevitably take place.

376. *In the air, and when the lungs are open, the three ventricles as well as the two auricles are all in play; and this alternately; namely, each auricle simultaneously with the intermediate ventricle, and then the two ventricles, or the right and left, simultaneously with each other.* Such appear to be the conditions; for when the two lateral ventricles are compressed, room is afforded for the intermediate ventricle to expand. The contrary is the case when the ventricles are dilated. This follows from a comparison of this heart with that which has two ventricles (n. 374. 2). For if the intermediate ventricle be only an extension of the canal of the pulmonary artery, its systole and diastole will coincide with the systole and diastole of the two auricles, and likewise with that of the pulmonary artery in the heart with two ventricles.

377. *The anterior large artery, which issues from the right ventricle, resembles the arterial tube of the embryonic heart with two ventricles.* For two arteries issue from the right ventricle of the former, of which the great artery, or the real aorta, is a little after divided in the usual way into a superior and inferior trunk. Then there is another large artery, which after pursuing an incurvated course for about ten finger-breadths, terminates in the inferior trunk of the great artery; not unlike what we find in the human foetus (n. 336), allowing for the difference in the space traversed, and for the circumstance that this artery is not extended from the perforated pulmonary artery, as in the foetus, because the pulmonary artery is sent to a third ventricle proper to itself, which is meant to be alternately closed and opened. Nevertheless it is proximately adjoined to the pulmonary artery.

378. *The posterior orifice between the right and left ventricles*



*resembles the foramen ovale of the fœtus.* It may be compared with the foramen ovale, although it is triangular, and overlapped in a peculiar manner, to the extent of one third of its diameter, with a valve hanging from the septum of the auricles, the other two thirds being impeded by a delicate network of white fibrils, which yet transmit the blood through their meshes. For the foramen leads from the right ventricle to the left, and back again; it does not however lead from one auricle to another, like the foramen ovale of the human fœtus, because in the latter no artery is extended from the left ventricle, but the blood, in order to flow, is first brought back into the right ventricle, which is the cause of the foramen being open in both directions. The anterior or round foramen of the heart of the turtle, which leads into the intermediate ventricle, or canal of the pulmonary artery, cannot be compared with the foramen ovale of the human fœtus, because it does not open into an aorta.

379. *Both of these, namely, the quasi foramen ovale and the ductus arteriosus, appear to be closed while the animal is under water, which is its own proper element.* If according to n. 376, all the three ventricles and the two auricles are in play when the lungs are open; and this, alternately; namely, each auricle simultaneously with the intermediate ventricle, and then the two ventricles, or the right and left, simultaneously with each other, it follows, that the sanguineous stream flows through the anterior or round foramen, that has no valve to close it, into the intermediate ventricle, and then back again from this ventricle; or fluctuates every time: it does not however flow so freely from the right ventricle into the left, and back again from the left into the right; for the foramen is stopped on both sides by the valve, which is not easily opened on the side next to the left ventricle, unless elevated by the blood flowing down from the pulmonary vein. For this reason it is attached close to its wall, to which indeed it would grow, unless the lungs as they are alternately raised, transmitted the blood through it. There may nevertheless for some short time be a certain flux or reflux through the beforementioned foramen, although thus partially obstructed; inasmuch as the valves close over only one third of its aperture. Thus there is an alternate pulsation, though each

is attended with dissimilar effects; the one takes place while the blood coming from the lungs first distends its auricle, the other while the auricle forces the ventricle to contract, as in the case of the heart possessing two ventricles.

With respect to the ductus arteriosus, or anterior artery of the heart, even this appears at that time to be closed. For it lies close to the pulmonary artery, and when this latter receives its blood over its valves, and can neither expel it into the lungs, nor reject it into the ventricle, the space appears at length to enlarge to such a degree as to press upon the proximate artery, and so to narrow it that it can admit no blood, and much less transmit any. It is not easy to conjecture by what other means this is effected, for the author we have referred to, makes mention only of a bundle into which the arterial trunks are closely collected above the base of the heart. Perhaps it is driven by some muscular or nervous sphincter, so that when the pulmonary artery is filled and turgescient, the other artery is contracted likewise above its valves. But I leave these remarks as mere conjectures. The contrary to what we find in the foetal heart with two ventricles, appears to prevail in the heart of this animal; in the latter, the foramen ovale and ductus arteriosus are closed when the lungs are constricted; in the former, they are closed when the lungs are open. For this animal is such that it can live under water, while land animals can live only in air. The former, therefore, has a heart with arteries and foramina so situated as to be adapted to its habits; the turtle enjoying the active and full life of its senses and limbs when it is under water (n. 383).

380. *And if this animal lived perpetually under water, the left and intermediate ventricles would combine into one, as in the case of fishes.* When the left ventricle, for instance, is constricted from the cause we have mentioned, and the blood is denied a passage through the pulmonary artery, the intermediate ventricle will be subject to a flux and reflux through the circular foramen, and the walls of the left and intermediate ventricle will each finally coalesce with that of the right ventricle. For when the lungs no longer admit or transmit blood, the necessity of a left, and also of an intermediate ventricle, which exist only on account of the pulmonary blood, ceases with the use.



381. *But if it lived constantly in the air, then, since the aorta cannot be carried into the left ventricle, or the pulmonary artery into the right, the anterior artery, or ductus arteriosus, could be closed; and the triangular foramen, which is analogous to the foramen ovale of embryos, could allow a passage from the left ventricle to the right, but not from the right to the left.* The reason is, that the blood is then constantly determined from the pulmonary vein to the left ventricle, from the left ventricle to the right, and so into the great artery. It is determined also from each cava into the right ventricle, then into the third or intermediate ventricle, and then into the lungs. Neither is there any flux of blood from the right ventricle into the left, because such a direction would be contrary to the stream. Hence the valves are probably opened in the direction of the current, and the valve which opens from the right to the left, and is suspended from the septum of the auricles, may be overspread with the larger, in accordance with the description given of it. And this, the rather, because the right side of the heart is itself also furnished with two other valves between the venous sinus and the right auricle. The case is different with regard to the left ventricle.

Lest therefore any confusion should arise in the circulation of the blood, in consequence of the frequent changes caused by the animal living under water and again in the air, or lest either circulation should become successive, as in those cases where the blood is conveyed through the foramen ovale and ductus arteriosus (n. 331, 334), it is provided that the venæ cavæ shall be first derived into a kind of large sinus, before entering the right auricle (n. 374. 5).

382. *This however affords no countenance to those who imagine that the foramen ovale of the fœtus opens from the left auricle into the right.* In the heart with three ventricles, the ratio is the inverse of what it is in the heart with two ventricles; for here the aorta is not in the left ventricle, but in the right, to which the blood is necessarily carried from the left. Nor again is the pulmonary artery in the right ventricle, but in an intermediate ventricle, into which the blood flows from the right ventricle: because there is no immediate exit from the left ventricle into any artery.

383. *By this mechanism of the heart of the turtle, we are taught that this animal enjoys the active and full life of the senses and muscles, when it is under water.* For when the anterior artery is closed that extends immediately to the descending aorta, or to the inferior members of the body (n. 377, 381), then the sanguineous wave ascends through the great artery towards the brains and their medullæ, from which it governs the forces of the members of its body.

384. *We are likewise taught, that an animal with such a heart, is stimulated by a kind of natural instinct to inhale the air with open nostrils, and frequently to plunge into the water, blindly falling into the cupidity which the necessity of its organization imposes.* It is of the utmost importance to its life, that the two ventricles of the heart should not unite into one, and that there should be no entire collapse of the lungs, which are excited by the blood enclosed above the valves of the pulmonary artery, to respire as often as the heart performs its diastole; also that none of the other members should be deprived of their motion by the continual pulmonary dilatation. We thus see why the animal, ignorant of the causes that excite it as by a blind impetus, is impelled to the pursuit of these different modes of life.

385. *We are likewise instructed, that such an animal, after its head is cut off, can nevertheless drag on a merely corporeal life for a long time, nay, even for some weeks.* For according to Caldesi, the turtle, when decapitated, carries its shell about for a whole fortnight after.\* The reason is, that it possesses a certain anterior artery, which enters into the aorta after an interval of ten finger-breadths, and provides with blood all the members of inferior rank; hence, notwithstanding the decapitation, the blood circulates through this artery, which continues open as long as the animal lives in the air (n. 379), and returns through the inferior cava, and has no need to flow through the aorta, which is now probably closed (n. 379). Moreover when animals of this kind are decapitated, the spinal marrow succeeds to the office of carrying on the functions of the body.

386. *Lastly, by this heart we are confirmed in the opinion, that it is the blood alone that opposes the valves, and removes them*

\* *Osservazioni anatomiche intorno alle Tartarughe marittime, d'Acqua dolce, et Terrestri*; 4to., Florence, 1687.—(Tr.)



*to one side*, (on which subject we shall speak in Chapter VII.) ; for instance, the two valves between the sinus of the venæ cavæ and the right auricle ; the two valves pendulous from the septum of the auricles ; and the two pendulous from each of the three arteries. From the lower part of the septum between the auricles, according to Morgagni, “two . . . valves hung forward, . . . and their inclination was such that it was easy to conjecture, that when the ventricles contracted, the valves must be raised by the compressed blood, and compelled to shut the auricles” (n. 373). The case is the same also with the semilunar valves of the veins in the body, which are subject to the action of the blood (n. 191), according to Wedelius,\* who shews that those valves do not act, but are only moved by the liquid ; and assigns mechanical reasons why one only, or several, are present, and can be present. This again confirms the truth of the proposition (n. 190—198), that the venous blood is pressed and presses in every direction.

\* *Propempticon de Valvulâ Venæ Subclaviæ Ductui Thoracico impositâ* ; 4to., Jena, 1714.—(Tr.)

## CHAPTER VI.

### THE PECULIAR ARTERIES AND VEINS OF THE HEART, AND THE CORONARY VESSELS.

387. LANCISI. "It is to be observed in the first place, that the coronary artery, which arises from the aorta within the pericardium, most generally by two branches, very rarely by three, or by one, (if by one, it immediately afterwards divides into two,) is so placed as to form an acute angle with the section of the aorta that lies between it and the heart; and therefore it may perhaps be thought,—as the direction of the motion of the blood propelled by the systole of the heart, is not in the same line with the direction of the coronary arteries, but on the contrary forms so acute an angle with them,—that only a very small quantity of the stream can flow at that time, and in that direction, into the coronary arteries. But on the contrary, &c. &c. . . . It should by no means be overlooked, that of the branches of the coronary arteries, (with the exception of those that nature dispenses to the adipose follicles of the heart, and to the trunks of the great arteries and veins,) the first are distributed to the auricles, and the subsequent branches to the ventricles: consequently the passage of the blood running through the coronary twigs from the aorta to the auricles, is a little shorter than that of the blood running to the ventricles. . . . It is to be observed that the coronary arteries, by their larger branches, which form wonderful anastomoses with each other, creep over the external surface of the heart, running partly like a crown about its base, and partly in straight furrows as it were from the base to the apex; but that they do not penetrate to the inner muscular substance of the heart except by the minutest twigs. It seems also worthy of remark, that the larger branches, which occupy the external surface of the heart, are covered throughout their course with adipose follicles and little bands; and thus are extremely lax and soft, and if slit up longitudinally with the scis-



sors, they are found to be marked on the inside by minute irregular rugæ; and on this account admit of being easily distended and enlarged both in length and breadth. . . . Again it is to be observed, that the coronary arteries have no valves at their immissaries;\* although Thomas Bartholin, because he happened to meet with valves once or twice, (as I myself likewise have done,) presumes that they are to be found always. And indeed arteries of this kind require no valvular barriers to prevent the blood from regurgitating into the aorta; since the constant pressure and struggle of the blood in the aorta, is powerful enough on every side effectually to counteract the return of the blood from the mouths of the coronary arteries. But this does not hold in the lesser branches of the coronaries, which dip deeply into the muscular substance of the heart and auricles; for here we find little sphincters and valves beautifully and abundantly distributed. (*De Motu Cordis*, &c., lib. i., prop. 39.) After attempting in vain by the introduction of a probe, and by other means, to find any valves either in the orifices, or the larger branches, of the coronary arteries, it occurred to us to examine some of the twigs proceeding from them, after having previously opened them with a lancet. Into these then we inserted a bristle, and on pushing it in the direction of the larger branches, we met with an obstruction. In order to prove to ocular demonstration what it was that impeded the further progress of the bristle, and prevented its entrance along the cavity of the branches, and to ascertain whether it was a valve, or anything else, we proceeded with extreme care . . . to separate the coronary arteries from the substance of the heart, together with the segment of the aorta from which they issued. These we detached with their large, lesser, and least and most delicate branches, to as great an extent as we could; and we then placed the whole tree of vessels in a basin of water. Having done this, we observed all the extreme vessels, both by reason of their minuteness and of the air they enclosed, spread about in every direction, and floating on the water, so as to present a beautiful appearance, like portions of windweed, anise, or fennel; and we remarked both in the larger and lesser series of tubes a variety of phenomena. We observed first, that the great stems of the coronary arteries, which surround the base of the heart, and reach to its apex, floated in a spiral order and with a spiral motion, and after they were taken out of the water, they could be extended to a much greater length than when they adhered to the heart. On injecting mercury into the coronary artery, it was curious to see the larger branches become corrugated, and the smaller strangu-

\* See n. 409, for an explanation of the terms *immissaries*, *emissaries*, &c., which frequently occur in this chapter.—(Tr.)

lated, as if by nervous threads. . . . When we slit up the trunks of the coronary arteries, and the larger branches proceeding from them, we found the interior membrane much whiter and thicker than in the other arteries, (in which the arachnoid membrane is plainly seen); and so much softer, that when we attempted to pull it off, it followed the fingers with more facility than in the case of any other artery. It appeared that this was the case, because nowhere in the body are the arteries placed in greater and more violent motion than in the heart; for which reason the external membrane, as well as the intermediate muscular membrane, falling as they do, so often and so strongly, into contraction and distraction, are in a manner disjoined and separated from the internal membrane; while the innermost membrane runs into numerous rugæ, which in some measure perform the office of valves, and prevent the return of the blood into the aorta, as well as its reaction or resistance *a tergo*. We observed branches proceeding from the trunks of the coronary arteries, and twigs from the branches, proportionally more numerous and abundant than in the arteries of any other muscle; and not without reason, for since the muscular planes and fasciæ are far more abundant in the heart than in any other muscle, it is necessary that each line and curve thereof, each bundle, and each fibre, should be tracked by little arteries of its own. We carefully noted the skill of nature in placing at the mouths of each of the larger coronary arteries, where they divided into the smaller, a kind of circular margin or border, and as it were a delicate sphincter. . . . But at the little mouths of the lesser and least arteries that are distributed through, and buried within, one or other of the muscular planes, we saw valves opposed, which in fact prevented the regress of the blood from the lesser arteries into the larger. This arrangement seems to me to conduce in a remarkable way to the systole of the heart. For when its fleshy fibres begin to be stretched, they are at the same time increased in bulk; . . . and hence we find that water injected into the coronary arteries, and diffused through the substance of the heart, never runs back even when the heart is compressed; the contrary being the case in the veins, through the mouths of which any liquid that is thrown in, soon regurgitates. But in order to see these valves clearly, we must select the small arteries, and introduce into them a fine probe, or a bristle, gently driving it the wrong way of the vessels, that is, toward the larger branches; for near each of the little mouths that open toward the trunks, we shall observe even with the naked eye, that the membranes of the valves are raised, and the point of the probe or bristle impeded and entangled. But if we still push on the probe, we shall find it clothed and covered with the membrane of the valve, which is thus ex-



panded by force. All these appearances are best seen in the heart of the horse; . . . for here the valves that hinder the passage of the probe, are raised in every one of the sections or origins of the smaller trunks, until they are either ruptured by force, or else opening out in a contrary direction, give way and sheathe the probe. In like manner small sphincters are here and there clearly observed in the twigs of the little arteries, like little knots, which are seen even in the last ramifications, so far as the microscope will enable us to follow them. (*Ibid.*, prop. 40). Nature is so variable and inconstant in locating the mouths of the coronary arteries, that a few dissections only, especially if made in the human subject, are sufficient to present us with many varieties. . . . In those persons who during life had a strong pulse, we generally found the orifices above the margins of the valves : in those who had a moderate pulse, we observed them in the confines of the valves, or one orifice placed above [the valves], and the other below, as Morgagni also has noticed : while in those who had had a small pulse, and particularly in women, we found them for the most part opening behind the margins of the valves. We have observed something similar, but much more evidently, in brutes ; . . . for instance, in horses, in which we have seen the orifices situated more frequently above than below the margins. . . . In dogs also these orifices open a little above the margins, and in our numerous experiments upon these animals, we have only once or twice found the same immissaries on a level with the borders of the valves ; the animals in these cases being gentle of temper and domestic. In slow-footed, languid animals, such as oxen and sheep, we saw the orifices buried below the margins of the valves. But whether any, and what, variety, in the motion and flow of the blood through the coronary arteries, is produced by the variety of situation in the orifices, is a question of no very easy solution. . . . The membranes of these valves are tendineo-muscular, moveable, and in great part free, but nevertheless attached to, and continuous with, the base of the heart, and in three places continuous with the parietes of the great artery. Thus when the heart falls into systole, these membranes, as parts of it, are necessarily a little contracted, and become shorter, as far as they can, both in length and breadth, &c. . . . In the vivisection of mastiffs, (which have the orifices of the coronaries above the margins of the valves,) when the thorax is opened and the pericardium divided, we have seen the coronary artery pulsating at the same time with the aorta, both being expanded and constricted simultaneously ; and in like manner when punctured, the jet of blood from both, and the interval between the jets, was synchronous. But in sheep, which have the immissaries of the coronary arteries placed under the valves, we saw the aorta begin

its diastole somewhat before the coronary artery, but both completed the diastole at the same time. (*Ibid.*, prop. 41.)

388. "We found nature often variable and inconstant with respect to the immissaries of the coronary arteries; we have now to observe that the same may be said of the emissaries of the coronary veins, which in fact open in the heart without following any ascertained law. Thus although they generally open within the sinus of the right auricle, near the cava, by two mouths, one superior, and the other inferior, yet sometimes they open only by one orifice, and this of large size, which immediately after separates into two; and not seldom they open by three orifices, which are always found proportionally somewhat smaller. We say proportionally, for there are certain fine and minute orifices of the coronary veins, many in number, . . . which vomit chiefly the blood returning from the roots of the larger veins and arteries, from the auricles, and from the base of the heart near and within a certain little venous canal, . . . [which is like an oblong valve placed upon many together of the little mouths of the veins.]\* We can assert that we have very frequently seen three large trunks of the coronary veins running to the right auricle, and eructating their fluids through the beforementioned orifices; two of the trunks occupying the posterior parts of the heart, and one of them ascending from the apex in a right line, the other creeping from the left auricle, and from the adjoining walls of the left ventricle especially. The third trunk we found occupying the anterior surface of the heart, and bringing back the blood from the bundles of fibres belonging to the right ventricle. Nor is there a frequent diversity only in the number and situation of the orifices and branches; but also, and to a very great extent, in the valve, which Eustachius describes as like a new moon in shape, the larger orifice of the coronary vein being covered with it as a lid. And although it is for the most part single and solitary, and shields and defends either one, or two together, of the mouths of the veins, yet it is sometimes wanting entirely, the large orifice of the coronary vein lying quite naked and open. . . . And not only is one lunular or crescentic valve sometimes seen, but sometimes two, to correspond to the two orifices of the vein; one valve being comparatively large, the other small, according to the size of the area of the orifices by which the trunks of the coronary veins open into the auricle. . . . The coronary veins distributed over the surface of the heart, appear to be somewhat more numerous than the arteries. . . . Those coronary veins that come from the fibres of the auricles, are shorter than those that come from the muscular texture of

\* See Lancisi, *De Motu Cordis*, &c., lib. i., prop. 36, expl. tab. v.—(*Tr.*)



the ventricles, so that by the same law by which the blood runs through the coronary arteries into the parietes of the auricles, sooner than into the parietes of the ventricles, it returns through the veins from the auricles sooner than from the ventricles. . . . We seldom find valves in the larger trunks of the coronary veins, but always in the smaller branches, as we found to be usual in the arteries. (*Ibid.*, prop. 42.)

“I am aware that the most celebrated anatomists of the present day, and especially Thebesius, . . . have shewn that the passages and tubules that convey the blood from the larger coronary veins into the ventricles, assist these veins necessarily, either always, or when occasion requires. . . . We seriously affirm, that the first gleam of light on this obscure subject, broke in upon us about nineteen years since, in dissecting the heart of a mastiff. In this case, having opened the right ventricle lengthwise, and sponged it clear of blood, we happened to grasp the left ventricle in our hand, and to press strongly against the septum; and we saw very minute and slightly red drops of ichor issue slowly from certain little mouths in different parts of the septum and its vicinity. This immediately led us to doubt, whether nature had not opened obscure passages for the transit of the blood, from the left cavity to the right, and *vice versâ*. But when afterwards I found, on opening the left ventricle, that the same thing occurred in it also, near the apex, as well as in other internal segments of the heart when strongly compressed, and especially where the veins had been secured, I was immediately roused to suspect the true nature of these diverticula. They are best shewn by the injection of liquids into the coronary veins. . . . If mercury be injected into the arteries of the heart in a healthy state, it is seen to pass through the pores and minutest openings of the ventricles, but it does not so plainly issue by little jets as if thrown in through one of the trunks of the coronary veins. . . . The open diverticula of the veins are conspicuous within the cavities of the heart, and the attentive anatomist will easily detect them, if, through the different mouths or emissaries of the coronary veins that open into the right auricle and into the top of the vena cava, he gently throw in either air or colored water, (for the trunks of the coronary veins have no valves): when he will soon perceive the injection not only oozing into the right and left cavities, in the form of bubbles and little drops, as it were of sweat, but sometimes gushing out in little jets. We selected more than once . . . the lesser mouth of a coronary vein, which appears under the larger mouth generally near the root of the cava, and which is framed to receive the blood returning from the posterior parts of the heart, and thus from the middle septum especially. The water gently injected into this orifice by the syringe, much to our

admiration was seen to pass under the columns themselves towards the apex of the left ventricle. In like manner, when air was thrown into another vein occupying the external and posterior part of the heart, we immediately observed the columns in the left ventricle tremulous and vibrating, and bubbles rising in different parts. We selected also a third posterior vein, the liquor thrown in through which, came out by certain most minute roundish openings existing in the internal tunie of the right ventricle, towards its apex and middle septum. Neither did we neglect the other branches of the veins, for we threw in liquids through the anterior coronary veins also, and saw the right ventricle evidently moistened, and the transverse column particularly, or the fleshy beam, bedewed with drops. So that I could no longer doubt the existence of an intimate communication between the coronary veins and the two ventricles. We chose for experiment the hearts of horses, or else of oxen, such as had been slaughtered. . . . But we must candidly confess, that in the human heart we have seldom been able to see (as some have verbally described, and even represented in plates) the liquids injected through the twigs, issuing from the foramina of the ventricles. In the hearts of horses and oxen, however, we have observed it very conspicuously. . . . We ought not here to omit to mention, that on the internal surface of the left auricle, certain small foramina occur, which are diverticula of those veins that creep along from the external surface of this auricle toward the right auricle. It is evident, therefore, from a variety of well-conducted experiments, that there are meanders, winding passages, and diverticula, leading from the coronary veins into each of the four cavities of the heart, and that the blood makes use of these as outlets. (*Ibid.*, prop. 44.) It is to be observed, that the orifices of the diverticula, which are numerous in both auricles and ventricles, are protected by no valves, but open freely and nakedly; so that others as well as myself have readily injected liquids with a syringe through these foramina, which liquids were diffused through the substance of the heart, or rather through the veins, and when they could not escape in any other way, regurgitated through the same orifices. . . . That the blood alternately goes in and out, with a kind of ebb and flow, through the beforementioned diverticula of the veins, seems to be proved by what we have observed in regard to the lips of these orifices. For these lips are not rough, uneven or edged, but always smooth and polished; making it probable, that the liquids smooth down the margins of these little mouths by their alternate passage to and fro, as it were by the chafing of a fine and delicate pumice. (*Ibid.*, prop. 46).

“When we injected mercury through the coronary arteries of the heart of a dog, we not only found the larger, smaller and capillary



branches that ramified over the external surface filled with the injection ; but in dissecting the ventricles, and the left especially, we saw the lacerti, columns and cords of the internal surface, beautifully distended by the mercury, so that they shone like silver, and presented the appearance of transparent tubules, which although perfectly sound, yet sweated all over with minute drops of mercury, and when cut into, let out the mercury in large quantities. (*Ibid.*, prop. 52.) The nerves are applied to, implicated with, and inserted in, the coronary vessels in a wonderful manner. . . . But although it should not appear from their anatomy, that the nerves surround the coronary vessels with an ivied twine, and are applied to, implicated with, and affixed to them in six hundred different ways, and thus assist in the alternate protrusion of the blood from the external to the internal parts, and from these to the interior passages, nevertheless . . . experiments would most clearly demonstrate that such is really the case. . . . If we take the heart of a man, dog, or sheep, we shall find it generally relaxed and flaccid, or as it were in a state of diastole, with the coronary arteries and veins very large and conspicuous. And if we slightly moisten it on the outside with boiling water, and inject it with the same, we shall immediately see it pass from diastole into strong systole, and the external coronary vessels become smaller and in a manner obliterated, while the nerves that more especially accompany and envelope the arteries, appear more conspicuous, and strive as it were against the coronary arteries.” (*Ibid.*, prop. 53).

389. LOWER. “The vessels that convey the blood into the parenchyma of the heart, are only two in number, but each of these soon divides into two other trunks. The orifices of the vessels first named, are situated about the beginning of the aorta, immediately beyond the semilunar valves. The vessels themselves are denominated coronary, because their trunks do not pass directly into the parenchyma, but make a circuit first, in order the more conveniently to unfold themselves in all directions, and so embrace and encircle the base of the heart. And although at the very origin they go away from each other to opposite regions of the heart, yet about the extreme parts they again meet, and here and there communicate with each other by open mouths, so that if any liquid be injected into one, it runs simultaneously through both. . . . But as there are two arteries that supply the heart with blood for the purposes of nourishment and warmth, so in like manner there are two veins, which from their course are also called coronary, that serve the purpose of bringing the blood back again. And lest any one should in future doubt whether the capillary veins open into each other, let him examine the cone of the heart of a calf,

or other new-born animal, in which these vessels are more obvious, and let him squeeze and drive the blood with the tip of his scalpel from the one vein into the other, and he will clearly see that the sanguineous liquid easily passes from the vein on one side into that on the other; and *vice versâ*." (*Tractatus de Corde*, &c., p. 12—14; 8vo., London, 1699.)

390. BOERHAAVE. "The heart has two [coronary] arteries arising from the aorta just above its semilunar valves, and which running in opposite directions, form one canal. This canal encircles the base of the heart, and sends off arterial branches, which variously anastomose with each other, and are spent in innumerable minute twigs, that pour out a humor in the form of dew, and pervade the whole surface of the heart, and together with the veins similarly distributed make up nearly all its substance. A quantity of fat lies externally between the vessels. The coronary arteries undergo diastole while the other arteries of the body are performing systole. But the veins pour their blood partly into the coronary veins, and so towards the right auricle, opening between it and the right ventricle; partly, by particular orifices, into the right auricle and ventricle immediately. These veins are emptied while the other veins of the body are filled." (*Inst. Med.*, n. 183.)

391. WINSLOW. "Besides the great common vessels, the heart has vessels peculiar to itself, called the coronary arteries and veins, because their trunks in a manner crown the base of the heart. The coronary arteries are two in number, and arise from the beginning of the aorta, after which they spread round the base of the heart, and send a number of ramifications into its substance. The exterior course of the coronary veins is much the same with that of the arteries, but they end partly in the right auricle, and partly in the right ventricle. They likewise terminate, but in smaller numbers, in the left ventricle, by the venous ducts that open in the fossulæ and lacunæ between the inequalities of the ventricles. Similar lacunæ are observed in the auricles between the prominent lines beforementioned.\* And in the great bag of the left auricle we find small holes that seem to have the same use. Of the two coronary arteries, (for there are seldom three,) one lies to the right, the other to the left, of the anterior third of the circumference of the aorta. The right coronary runs in between the base of the heart and the right auricle, all the way to the flat surface of the heart, constituting half the coronal circle. The left coronary passes between the base of the heart and the left auricle; and before it turns on the base, it sends down along the convex surface of the heart a principal branch

\* See *Exp. Anat.*, *Tr. de la Poitrine*, n. 67.—(*Tr.*)



in the interstice between the ventricles. Another principal branch issues from the union of the two arterial semicircles on the flat side of the heart, and running to the apex, there meets the former branch. The coronary veins are distributed exteriorly much in the same manner. Their trunk opens principally into the right auricle by a particular orifice furnished with a little semilunar valve. All the coronary veins and their ramifications intercommunicate, so that if we blow through a small hole made in any one of them, having first compressed the auricles and large arteries, we observe that the air swells all the vessels, and the ventricles likewise by passing through the venous ducts." (*Exp. Anat., Tr. de la Poitrine*, n. 70—73.)

392. RUYSCH. "Authors have given the name of coronary to the arteries that supply the substance of the heart; and deservedly; because arising from the root of the aorta above the semilunar valves, they surround the base of the heart. But no one hitherto has perfectly delineated their numerous offsets and divarications, so as to shew them distinctly, . . . much less has any one delineated the arteries that spread their innumerable twigs through the auricles: although these arteries, termed by me the auricular arteries of the heart, proceed from the coronary artery on both sides, and are distributed through the auricles in all directions; their use being, to furnish the auricles with the quantity of arterial blood requisite for nutrition and warmth. The before-mentioned coronary arteries, in their distribution through the heart's substance, furnish arterial blood not only to the heart and auricles, but also to the tunics of the root of the trunk of the aorta; which fact again I have not seen observed or delineated by other authors." (*Epist. Anat.* iii.)

393. The course of these vessels is well shewn in Ruysch's Figures: thus those which are considered arteries, and which proceed nearly from opposite sides of the aorta, encircle, in the manner of a crown, the whole circumference of the heart, both breadthwise, and longitudinally [from the base] to the apex, reuniting [with each other to complete the circles]. From each of the trunks, shortly after their origin, a considerable branch is reflected, which runs over against the root of the aorta below like a subtense, and meets with the branch of the other side, and gives off another branch, which descends nearly along the septum on the left side of the heart, and divides into two twigs that unite with the former coronary artery. From the same subtense at the right side another considerable branch passes down, besides others from the coronary trunk itself, but all of which intercommunicate. It is worthy of notice, that from the subtending arc offsets rise to the aorta itself, although not to any great distance. In like manner from the right side

of the same subtense, a ramification passes to the right auricle, and a similar one from the left side to the left auricle; but which anastomoses at some distance from the aorta with the coronary artery, that, namely, which surrounds the heart. (*Epist. Anat.* iii., tab. iii., fig. 1, 2, 3.) It is very desirable that the reader should examine Ruysch's other Figures, which will teach him more than any mere verbal description. See, for instance, the figure representing the flat side of the heart [where it lies on the diaphragm], in which two [venous] branches are delineated, running from the opening in the right auricle, one of which slants off to the artery before described, in order to gain its side, and the other passes down nearly from the same point to the surface of the heart. (*Thes. Anat.* iv., tab. iii., fig. 1.) See also Eustachius, *Tabul. Anat.*, tab. v., fig. 7, 8 [Cologne, 1716], exhibiting the ramifications that run from the right auricle to the body of the heart. In fig. 7, the author shews how the veins on both sides follow the same course as the arteries.

394. MORGAGNI. "I have sometimes noticed a loss or separation [*dissolutionem*] of the fibres\* in the extreme border of the lunular or crescentic valve, which, varying in size, is prefixed to the coronary vein; and I remember once to have seen this valve disjoined from the mouth of the vein, or at any rate connected to it merely by cornua. (*Advers. Anat.* v., Anim. 22.) Fantoni 'apprehends that the blood must be sent into the coronary arteries, rather by the contraction of the aorta than of the heart, because those arteries are most conveniently situated for the reception of the blood driven back by the aorta, and also because the blood flies with such force and rapidity from the heart into the arterial trunk, that it seems impossible for a portion ever so small to turn back at the time [of the heart's systole] into the coronary arteries.' I should certainly be of the same opinion, unless I supposed the aortic trunk to be so full of blood, that by its reaction the blood that is sent from the heart is driven forcibly against the sides of the trunk, (as the diastole of the latter shews,) and therefore, as it would appear, can rush into the coronary branches. A view which I the more readily put forward, as I find this learned . . . anatomist acknowledging shortly afterwards, that 'all are disposed to think, not without reason, that the coronary artery must also receive blood during the systole of the heart.' Nor does it seem that this can possibly be denied, when the orifices of these arteries are above the border of the valves. But when they lie entirely below it, and are consequently blocked up at every

\* Morgagni is here speaking of certain "tendinous fibres" connected with the valves of the great vessels.—(*Tr.*)



systole by the valves, (which in fact are pressed closely against them by the blood rushing from the heart,) it appears necessarily to follow, that if afterwards the artery contracts, and pressing back the blood, displaces and unfolds the valves, the blood may be then admitted into the above orifices. And in this case we must assent to the learned Boerhaave, where he says, that ‘the coronary arteries undergo diastole while the other arteries of the body are performing systole.’ But although this, as I have stated it, appears to be the case at first sight, yet perhaps on closer consideration it will scarcely seem probable, that in a matter of such great moment, so great a variety should exist in different individuals. And we must also bear in mind, that as in one and the same subject one orifice of the coronary arteries is sometimes found above, the other below, the border of the valves, so the same variety must be admitted to exist in one and the same heart at one and the same time. What then shall we say? We must adopt one or the other of these statements; and since the orifices of the coronary arteries, in those cases where they lie completely behind the valves, can scarcely admit the blood except during the heart’s diastole, it is certain that nature, in order to be consistent with herself, must be presumed to have prescribed the same conditions in all instances; and this the rather, because although these arteries open above the valves, yet not only are they, as Fantoni intimates, ‘most conveniently situated for the reception of the blood driven back by the aorta,’ and not of that driven forwards by the heart into the aorta; but during the time when the blood is thus driven forwards, since it is driven by the heart’s contraction, it seems that they can admit little or none of it, on account of the strong constriction of the fibres of the heart itself. But those sagacious authors, the surmise of one of whom, and the opinion of the other, have drawn me into this subject, will best settle all these points: for my part I do not decide upon them. (*Ibid.*, Anim. 25.) We have no hesitation in stating, that of the nine last bodies which, one after another, we have inspected, for the purpose of repeating observations upon these valves, five did not exhibit those inferior (I do not say superior) orifices represented in our figure: in two of them, while one orifice (as represented by us) appeared above the border, the other orifice was in one case above, in the other below it. Scarcely therefore in two instances were both orifices hidden within the border. Thus, out of eighteen orifices, not more than five lay hid behind the valves; the other thirteen were conspicuously above their borders. . . . This I state the more readily, because I am sure it is well known . . . that the same thing has been observed by those experienced anatomists, Bartholomæus Eustachius, Richard Lower, and Raymund Vieussens. For in their Plates . . . they,

in common with Andreas Vesalius and other learned professors, . . . have depicted both orifices of these arteries above the borders, and most of them have delineated another orifice also at the sides of the valves." (*Ibid.*, Anim. 26.)

395. VERHEYEN. "The heart has veins and arteries peculiar to itself, which are called coronary, because they surround the base of the heart like a crown: from which crown they send smaller branches through the whole of the substance of the heart. The coronary arteries are two in number. They arise from the beginning of the aorta under the semilunar valves, and although they run to opposite regions of the heart, yet in their course they again meet, and inosculate to form as it were a single vessel. The larger orifice of the coronary vein is in the vena cava beside the right auricle; from this point the vein runs to the left part of the heart, and at length terminates by various little mouths in the cavity of the right auricle. . . . The branches proceeding from the coronary veins and arteries towards the apex of the heart, anastomose with each other in different places—the venous branches with the venous, and the arterial with the arterial—so that often it is impossible to determine to what large branch the smaller branches properly belong; a circumstance which I have elsewhere mentioned as occurring all over the body, although nowhere is it so palpable as in the heart. When I say that these vessels are distributed through the whole substance of the heart, I mean to include that they supply the auricles also. (*Corp. Hum. Anat.*, lib. i., tr. iii., cap. viii.)

396. "Vieussens brings forward certain curious and notable experiments. . . . First; having tied the trunk of the vena cava both above and below the right auricle, and also the pulmonary artery and veins, he injected tincture of saffron made with brandy into the left coronary artery. A portion of this tincture was without violence soon made to pass through the branches of the coronary artery into the entire substance of the left auricle, as shewn by its inflation, tension, and yellow color: and from the substance of this auricle the tincture fell into its cavity, and so into the pulmonary vein and left ventricle, without a drop passing into the right ventricle. This fact, he thinks, proves that the left auricle has no veins, because if it had any, the tincture would have run through them, and been transmitted into the right auricle and ventricle through the vena cava, where all the veins of the body meet either proximately or remotely. He then made other injections with the same tincture, at one time into the right, at another time into the left coronary artery, and he saw the liquid pass respectively into the right or left ventricle, not omitting also the right auricle. Of the left auricle we have already spoken. He afterwards found in the cavities of



the heart when macerated in water, a great number of particular passages terminating on the inside of the same cavities, which passages he calls fleshy ducts, and says that they are continuous with the arteries. He concludes first, that the coronary veins with their branches are entirely superficial to the heart, which he further proves by the tincture injected into them not tinging its inner substance. Secondly, that these veins do not communicate immediately with the superficial arteries of the heart, as do the veins in the liver, spleen, and some other parts ; since the communication in the heart is effected by the intervention of the fleshy ducts, which proceed from the sides and extremities of the superficial arteries of the heart, and reach to the sides of its veins.

397. "Vieussens stated, that all these particulars were as well seen in the hearts of the ox and sheep, as in the heart of the human subject; and therefore I took an ox's heart, and traced the pulmonary vein from its orifice towards the left auricle, and after removing the fat, I soon met with a branch, which arising immediately from the coronary vein, extended through the substance of the auricle ; and on proceeding further, I discovered five such branches in one subject, and eight in another. . . . With these eight venous twigs, there were eight corresponding arterial twigs, arising directly from the left coronary artery, and lying near the veins, under the fat ; but I cut them off to get a better view of the venous twigs. Having seen and examined these, I proceeded to trace the coronary vein, and saw it at length, by a large branch, or little trunk, enter the substance of the right auricle, and there divide immediately into two branches of nearly equal size, namely, into a right and a left. From about the place of division, but more from the right branch, two small twigs came off, which extended through the substance of the auricle. But the larger branch immediately entered its substance, and sending off some twigs, opened into its cavity by a considerable orifice, which not only gave vent to liquid, but also to a probe passed into the vein. And through the same orifice I afterwards inflated the vein itself, as well as many of its small twigs distributed through the heart's substance. I also found two other venous orifices in the cavity of the same auricle : these were the orifices of offsets of the above vein, but which offsets I could not well see on account of the sulcated character of the auricle. . . . The left branch sent its branches far and wide through the substance of the auricle, and some of its twigs terminated in the cavity of the auricle, others in the vena cava. The above veins had arteries corresponding to them proceeding from the right coronary artery, but the correspondence was not so exact in point of number and size as in the left auricle. . . . By these experiments I shew that . . . the auricles of the heart are cer-

tainly not destitute of veins. . . . In the same ox's heart, I fixed upon the largest branch of the coronary vein, which lies nearly in the place where the external wall of the right ventricle joins in front with the middle septum, and having tied the other large branches to prevent the injected liquid from passing at once to the coronary vein, I threw in water through the grand branch, and it readily found its way to the cavity of the right ventricle, and escaped by the orifice of the divided vena cava. In order to see the water escaping, and to observe the places from which it issued, I opened the right ventricle in the part opposite to the course of the vein alluded to, lest I should wound the large branches of the latter, and the liquid finding an easier exit elsewhere, should not pass to the ventricle. But notwithstanding this, it escaped so largely from the orifices on the inside of the ventricle, that there was no seeing the places from which it came. I then inserted a small tube, and blowing through it, the air came out with water in the form of bubbles, and shewed the places excellently. The orifices from which the air escaped were very numerous ; some of them were overlaid with the internal membrane of the heart, which thus acted as a valve ; others, instead of this valvular provision, were inserted obliquely. On dissecting some of the larger orifices from which the water issued, I saw at the sides of them a number of minute foramina, just as Vieussens himself has described. In some of them there were four or five foramina, in others fewer, all of which beyond doubt were orifices of vessels discharging blood into the ventricle. Next I tied the larger vein, which I had inflated, and selected another belonging rather to the left ventricle. This was filled with injected water, but whether air or water was thrown in, I could not observe more than four orifices out of which either issued. I tried the same experiments with the coronary arteries, and observed that water or air sent into the vein, passed into the cavity of the ventricle, through the orifices which opened there, with more readiness and in larger quantity than when sent into the artery. . . . Here I first remarked, that the vein commonly known as the coronary, (which opens with a wide orifice in the region of the right auricle, near the foramen ovale and the cicatrix thereof,) is almost entirely spent in branches that run to the apex of the heart, (or if we may so speak, is constituted of branches proceeding from the apex,) the last of which is the one into which I injected the liquid, &c. So that only a small branch runs on from it to the right auricle, and as it begins to approach the auricle, is again enlarged by the accession of fresh twigs, until at length it divides into branches, which after distributing twigs through the substance of the auricle, open, as I before said, by a variety of orifices into its cavity. As then the coronary ar-



tery is constituted of two arteries, which run from their origin in opposite directions, and inosculating, constitute the more slender part of the before-mentioned artery, so also the coronary vein has in a manner two trunks, namely, one that opens into the vena cava over against the auricle, and one that terminates in the cavity of the same auricle . . . in which also some of the smaller branches likewise terminate. . . . It is evident therefore from the preceding observations, that a vast number of vessels open directly into the cavities of the ventricles and auricles, (this at least is true with respect to the right auricle,) and indeed many more into the right ventricle and auricle than into the left. . . . I conclude . . . that those fleshy ducts [of which Vieussens speaks], . . . are in reality venous. I inserted a bristle into some of the little orifices of these vessels, with a view to ascertain their course, and cautiously removing the fleshy substance of the heart, I saw the bristle deviate in certain places, and perforate the above substance; while in other places it was still lodged in certain exquisitely fine vessels, whose course I could trace no further in consequence of their curvatures. A vast number of the little orifices would not admit the bristle at all. . . . I am in no way influenced by the experiments that Vieussens brings forward to shew that the inner substance of the heart is destitute of veins, because it is not colored by tincture of saffron injected into the coronary vein; for when common water is thrown into the latter, it passes in large quantities, and by numerous outlets, into the cavity of the ventricle; and indeed much more easily than when thrown into the coronary arteries. It is clear, however, that in these veins there are no valves, since liquids injected through the larger branch or trunk, pass readily into the smaller branches. From which I conclude, that the blood in these veins does not always pursue the same course, but issues out into the ventricles when these are emptied, but when they are filled, and unable to receive any more, this blood then runs away into the larger branches of the coronary vein, and so is carried on through the trunk, to the vena cava, or right auricle." (*Ibid.*, cap. ix.)

#### INDUCTION.

398. THE coronary vessels of both kinds, arterial as well as venous, arise from the heart itself, and not from the beginning of the aorta. For there are little columns and lacunæ in the ventricles and auricles; there are fleshy ducts, and there are motive fibres. The blood flows from the heart into the lacunæ, especially under the columns; from the lacunæ it is expressed into the fleshy ducts; from the fleshy ducts into the fibres; from the fibres into the coronary vessels, both arteries and veins; from the coronary vessels, either through two foramina into the aorta, or through one large foramen into the right auricle, or through several small foramina into the same: but the superfluous blood in the coronary vessels runs back into the lacunæ and ventricles.

All these vessels depend entirely on the action of the heart, in the stream of whose motion both they, and the motive fibres, and fleshy ducts, as well as the lacunæ of the ventricles and auricles, are set and disposed. From which it follows, that all the vessels that occupy the surface of the heart are venous, the arteries corresponding to which are in the substance of the heart.

Such then being the origin of the coronary blood, it follows, that the superficial vessels, commonly called coronary, perform their diastole when the heart performs systole: and in like manner that the superficial vessels of the auricles, perform their diastole when the auricles perform systole; and *vice versâ*. But



as many anomalies occur in the auricles, and in the right auricle particularly, so, in order that the auricular blood may find an outlet in all cases and under every circumstance, a number of orifices are provided, through which this blood can be thrown out, suitably to all diversities of state.

If we compare the origins of the coronary vessels with the outlets of the same, it will be evident that the blood of the right side of the heart is transferred immediately into the aorta, and the blood of the left side of the heart into the right auricle ; much as was the case in foetal life by means of the foramen ovale and ductus arteriosus ; shewing that the coronary vessels and their mouths, relatively to the determinations of the quantity of blood running through them, are substituted in place of the foramen ovale and ductus arteriosus ; the channel and mode of circulation only being changed. And this, in order that the superfluous quantity of arterial, or the superfluous quantity of venous blood, in this place of concurrence, may not injure or destroy the natural state of the kingdom, subject as it is to such frequent mutations.

Hence it is clear, that neither the motion of the heart, nor the circulation of the blood, can subsist for any length of time, unless the peculiar vessels of the heart that discharge the blood into the aorta, and those that discharge it into the right auricle, pursue a perfectly distinct course, and have no communication with each other. Were they conjoined, the same effect would ensue as if the septum between the ventricles were perforated.

Meantime, whoever attentively examines and considers the origin, progression and outlets of these vessels, will see in them, and consequently in the heart, an image and representation of the state of the body and animal mind. In which respect numerous affections may not improperly be attributed even to the heart, according to the usage of common discourse.

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399. *The coronary vessels of both kinds, arterial as well as venous, arise from the heart itself, and not from the beginning of the aorta.* So far as I am aware, all the learned are of opinion, that the peculiar or superficial vessels of the heart, or as they are commonly called, the coronary vessels, are partly arterial and partly venous ; and that the arteries arise from the beginning of the aorta, and the veins terminate in the right auricle. The only question among them is, whether the blood of these vessels flows in from the aorta at the time of its systole, or of its diastole. Indeed the very position of the orifices under the semilunar valves of the aorta, so perplexes the mind, that it appears imprudent to decide either one way or the other upon the subject.

400. There is scarcely anything in the heart more beautiful than these valves, which are placed at the root of the aorta, or at the extremity of the left ventricle, and are like little nests built with consummate skill, and neatly fastened up with little knots, clasps, girths and tunics. The coronary orifices lie close to the borders of these valves, sometimes higher up, sometimes lower down : see them beautifully delineated and described by Morgagni, Verheyen, and other anatomists. But dismissing this subject, I had better now refer immediately to anatomy, and other sources of proof, which forbid me to conclude that the blood is conveyed by this way to the surface of the heart.

401. Anatomy, I say, forbids. For, 1. When the heart is constricted, and the aorta expanded, the blood cannot pass to the surface of the heart either through one orifice or the other, (for there are two,) because at this time the valve is carried up, and the orifices are closed by its outspread curtain. 2. Nor can the blood pass through either orifice when the heart is expanded and the aorta compressed, because at that time the torrent is driven onwards through the arteries, so that none but the superfluous or refluent portion can regurgitate into the orifices, which it must do without impetus, or power of forcing itself in. On this subject Morgagni has the following learned and judicious observations : “ What then shall we say? We must adopt one or the other of these statements ; and since the orifices of the coronary arteries, in those cases where they lie completely behind the valves, can scarcely admit the blood except during the heart’s diastole, it is certain that nature, in order to



be consistent with herself, must be presumed to have prescribed the same conditions in all instances; and this the rather, because although these arteries open above the valves, yet not only are they, as Fantoni intimates, ‘most conveniently situated for the reception of the blood driven back by the aorta,’ and not of that driven forwards by the heart into the aorta; but during the time when the blood is thus driven forwards, since it is driven by the heart’s contraction, it seems that they can admit little or none of it, on account of the strong constriction of the fibres of the heart itself. But those sagacious authors, the surmise of one of whom, and the opinion of the other, have drawn me into this subject, will best settle all these points: for my part I do not decide upon them” (n. 394). 3. But it may be said, that one of the orifices opens above the border of the valve, and that through this the blood may flow, while the other lies concealed. For Morgagni again observes: “We have no hesitation in stating, that of the nine last bodies which, one after another, we have inspected, for the purpose of repeating observations upon these valves, five did not exhibit those inferior (I do not say superior) orifices represented in our figure: in two of them, while one orifice (as represented by us) appeared above the border, the other orifice was in one case above, in the other below it. Scarcely therefore in two instances were both orifices hidden within the border. Thus, out of eighteen orifices, not more than five lay hid behind the valves; the other thirteen were conspicuously above their borders. . . . This I state the more readily, because I am sure it is well known . . . that the same thing has been observed by those experienced anatomists, Bartholomæus Eustachius, Richard Lower, and Raymund Vieussens. For in their Plates . . . they, in common with Andreas Vesalius and other learned professors, . . . have depicted both orifices of these arteries above the borders.” (*Ibid.*) And Lancisi says: “In those persons who during life had a strong pulse, we generally found the orifices above the margins of the valves: . . . while in those who had a small pulse, . . . we found them for the most part opening behind the margins. . . . We have observed something similar, but much more evidently, in brutes. . . . In dogs . . . these orifices open a little above the margins. . . . But whether any, and what, variety, in the motion and flow of the

blood through the coronary arteries, is produced by the variety of situation in the orifices, is a question of no very easy solution" (n. 387). But granting that both, or either, of the orifices, may be partly, or, as rarely happens, wholly above the margins of the valves, as they appear in the flaccid heart after death, still we must remember, that the valvular tunic, though now dead and contracted, is so capable of elongation, that the slightest force is sufficient to extend it over the orifice; as we may see by softly passing the finger over the tunic, which will then not only close the foramen, but reach beyond it to the distance of some lines, as I myself have found upon experiment in the hearts of more than thirty animals. This will appear to be the more certainly the case, when we consider, that at the time when the systole of the heart presses the blood thither, the ventricle comes nearer to its artery, and thus enables the valve to move higher up: and at the same time the living volume of blood in the artery lays the valve flat, and extends the wall to which it is affixed, while the orifices remain in their place. "The membranes of these valves," says Lancisi, "are tendineo-muscular, moveable, and in great part free, but nevertheless attached to, and continuous with, the base of the heart, and in three places continuous with the parietes of the great artery" (n. 387). He has also carefully observed the manner in which these valves are attached to the walls of the aorta. "In the *post mortem* examination of children,"\* says he, "we found each connexion of two of the valves together, with the aorta, exhibiting a very analogous appearance to the clitoris in female abortions, for raised and crested oblong sutures adhered to the arteries, with which they were united by firm and strong bands of carneo-tendinous fibres, conveniently placed in each of the curvilinear angles of the valves; the loose borders of the valves being thereby attached to the more solid walls of the arteries. But these fibrous bands are produced further, and joined with the fascicles of fibres that . . . constitute the circular tendons." (*De Motu Cordis*, &c., lib. i., prop. 33.) From this description it is very evident, that when the artery swells and is pushed forwards, the valves are extended over the orifices, and that at the same time

\* Lancisi is here speaking of his observations in the bodies of children who died after attacks of hectic fever.—(*Tr.*)



the orifices themselves are narrowed to actual closure on the side next the base of the heart from which they proceed and open. Consequently when the heart is performing its systole, and the large artery at the same time, its diastole, the valve pushed forwards from the heart, and stretched out from the artery to a still farther extent by the rapid current of the blood, completely keeps out the flying wave by impenetrable bolts from the lips of either orifice: an effect which would not result with such certainty if the valves were not tied up and suspended in the manner we have described. At least if the semi-extended valve remained over its orifice or cavity, as plates represent, and the orifices were open in the way commonly imagined, the valve would give inwards every time the aorta pulsates and expends its forces in propelling the blood; that is to say, a hundred thousand times a day; when yet no trace of this perpetual inflection is seen in this part of the valve. 4. Moreover the law of nature, constant in its causes and effects, forbids our attributing to one heart, or to one of two orifices in the same heart, what is evidently denied to the other. 5. Yet although it be not the fact, let it be granted that each orifice is perfectly open above the margins of the valves, as Lancisi observed in mastiffs. Let us see then whether at the time of the systole of the heart, or the diastole of the artery, any blood can pass from the aorta through this passage into the coronary vessels. Now we observe that there is a canal running from the coronary trunks to the aorta over no small length of course, athwart the substance of the base of the heart, and so situated, directed, and inserted, that when the ventricle expels its blood into the aorta, it pushes forward that part in which the duct is excavated; and at the same time the aorta swelling, presses upon it, so that the passage now remains intercepted as far up as its place of contact with the aorta; and hence although the bolt be turned back from the catch, that is to say, although the orifice be laid half bare of its covering, nothing will pass through the narrowed intervening canal before the cardiac motion be again changed. "It is to be observed," says Lancisi, "... that the coronary artery ... is so placed as to form an acute angle with the section of the aorta that lies between it and the heart; and therefore it may perhaps be thought,—as the direction of the motion of the blood

propelled by the systole of the heart, is not in the same line with the direction of the coronary arteries, but on the contrary forms so acute an angle with them,—that only a very small quantity of the stream can flow at that time, and in that direction, into the coronary arteries. But on the contrary, &c. &c.” (n. 387.) A similar law obtains with regard to the duct between the base of the heart and the large coronary orifice of the right auricle; for the systole of the right ventricle is performed in the same manner as the systole of the left ventricle; so that it would appear that one foramen is opened by a force and according to a law similar to that by which the other is opened: hence the action of one being given, that of the other is given. And on both sides the foramina are placed as it were beside the centres of the two motions; namely, of the ventricles and *venæ cavæ* on one side, and of the aorta on the other; so that the foramina on both sides are at once compressed and closed, and at once drawn apart and opened. 6. Since, therefore, during the systole of the heart and the diastole of the great artery, the blood cannot be forced into the coronary vessels, there may perhaps be some room for doubting, whether it does not return as soon as the heart returns to its diastole, and the aorta to its systole, according to the second clause of this article; for the valves being then thrown back, and the base of the heart also receding, the orifices are laid bare and open. But still this would not suit the artery when it has sustained a loss of all its forces. It would be to claim for it a new action altogether different from what it exercises on the ramifications of the system; nay, it would be to claim for it, after the discharge of all its functions, a stronger, inverted, and retrograde action, upon a body the most muscular of any, after having discharged all its functions; especially since the arterial coronary vessel is distinguished by no muscular circles, but merely by little *rugæ* and folds of fibres; so that it cannot spontaneously propel the wave it has received, like the arteries of the body (n. 182—189). The whole parenchyma of the heart is then also in a state of general expansion, and hence the vessels themselves are generally rather expanded by the extension than opened. 7. To this cumulative experience we must add, that neither do the so-called arteries anywhere throughout the surface of the heart communicate with the veins, nor the



so-called veins with the arteries; as we usually find in the body in general. A tincture injected into the arteries never colors the veins, and that injected into the veins never colors the arteries; but if the veins were empty, they would continue empty after the arteries were injected. In this respect the former have not the condition or character of arteries, nor the latter of veins; a circumstance which indicates rather that both classes of vessels are similar in kind, and arise from the heart and not from the aorta.

402. We have then abundance of arguments from anatomy itself, to weaken the common opinion respecting the coronary vessels. But more than this, we observe, that to grant to these vessels only two inlets, and not always even two, into the aorta, would be to expose the heart itself (which is the purveyor of blood to the whole body), or rather the muscle of the heart, to dangerous hazard, and to suppose that it holds its life by tenure from its own artery; when yet nothing demands more present abundance and supplies of the blood, which is its own property, than the heart. If the motive fibre of the heart should lie idle, in consequence of the blood by any chance failing the left ventricle, it would no longer have the power of erecting or arousing itself; for it could no longer demand of the aorta what the aorta had not to give; its motion therefore would be soon postponed indefinitely, and itself consigned to certain death. Moreover, all that portion and all those motive fibres where we find no arteries, but only veins, (for instance, nearly throughout the right ventricle,) when destitute of arterial blood, would never be excited to action. It makes little or nothing for the argument to say, that one vessel is an artery, because its orifices open into the aorta, or origin of all the arteries, and that another is a vein, because it opens in the right auricle, or place of termination of all the veins; since the right ventricle as well as the left, and primarily also the foramen ovale, are situated at the beginning of the arteries and termination of the veins. But for the sake of distinctness, I will still call the coronary vessels that communicate with the aorta, arteries, and those that communicate with the auricles, veins; according to the common usage. But, if these vessels proceed from the heart, it is asked, from what portion of it do they come?

403. *For there are little columns and lacunæ in the ventricles and auricles.* This is plain from the bare inspection of the inside of the heart, in which we at once see eminences, little caverns, inequalities, as it were largish and lesser plicatures, especially in the right ventricle; in which indeed, in the heart of the sheep, I have reckoned more than fifteen, besides the fleshy eminence or column which Lancisi calls “the transverse column or fleshy beam” (n. 388). In the left ventricle, however, these columns, and the lacunæ under them, are few in number. In the auricles they are numerous, since that part which is properly the auricle, and projects beyond the border of the ventricle, is a fimbriated structure consisting of scarcely any other than similar open cavities. These columns, with the lacunæ under them, appear as if they arose from the corrugated internal surface of the heart, and hence from its alternate compression and expansion; for some of them are straightened out when the heart is drawn asunder, while some are constricted by lacerti. They are moreover guarded by tricuspid valves of their own, as those occupying the highest place in the right ventricle; and if carefully inspected, they are found to be receptacles and diverticula of the blood, and so many ventricles and chambers into which the heart is subdivided.

404. *There are fleshy ducts, or blood-conduits.* In these lacunæ and folds, we may everywhere see orifices that penetrate into the substance of the heart. There are some that have leaning roofs or walls. In some places there are more, in others fewer. There are some that are hidden, because in the smooth parts of the heart they are overlaid with its innermost membrane. These ducts are divided, at no great distance from their orifices, into several others, and these again into still more, and thus they ramify through the fleshy substance of the heart. According to Verheyen, Vieussens relates, that “he . . . found in the cavities of the heart when macerated in water, a great number of particular passages terminating on the inside of the same cavities, which passages he calls fleshy ducts, and says that they are continuous with the arteries” (n. 396). And Verheyen himself says, [speaking of his inflation of one of the coronary veins]: “The orifices from which the air escaped were very numerous; some of them were overlaid with the internal mem-



brane of the heart, which thus acted as a valve; others, instead of this valvular provision, were inserted obliquely. On dissecting some of the larger orifices from which the water issued, I saw at the sides of them a number of minute foramina, just as Vieussens himself has described. In some of them there were four or five foramina, in others fewer, all of which beyond doubt were orifices of vessels discharging blood into the ventricle" (n. 397). The same thing obtains in the auricles: in the right auricle there is a large and oblong lacuna, with its common lacunar or valve, and under it a number of oscula. This valve is figured by Lancisi, *De Motu Cordis*, &c., tab. v., and the following is his description of it: "There are certain fine and minute orifices of the coronary veins, many in number, . . . which vomit chiefly the blood returning from the roots of the larger veins and arteries, from the auricles, and from the base of the heart near and within a certain little venous canal, . . . [which is like an oblong valve placed upon many together of the little mouths of the veins]" (n. 388). Several of them have been noticed by our authors, for which see especially their plates. *And there are motive fibres*; for the heart in its whole compass is muscular and fleshy.

405. *The blood flows from the heart into the lacunæ, especially under the columns.* For these lacunæ are so placed as to receive the first-coming blood, and as soon as the heart falls into systole, they involve, enfold, and enclose it, and like subaltern chambers and sinuses, enter on and complete their diastole and systole while the common ventricle is performing the same. They are also placed in an averted or oblique position relatively to the great foramen of the ventricle and canal of the artery, so that they do not again let off the blood once enclosed: moreover, they nearly all open by the side of the transverse column or beam, near the septum of the ventricles, towards which septum the heart compresses itself on both sides, while it is performing its systole. Thus these lacunæ necessarily serve as receptacles and diverticula.

406. *From the lacunæ it is expressed into the fleshy ducts; or into the mouths or oscula opening under the columns* (n. 404); for there is no escape in any other direction; it cannot escape into the common cavity or ventricle, which is now in a state of

systole, and compressed toward the septum ; add to which, that the muscular flesh of the walls and columns urges it onwards. The lacunæ are averted from the great orifices, some are also furnished with a common valve, or instead of it, the ducts receive an oblique insertion, and immediately divide into smaller ramifications. The blood is consequently expressed *from the fleshy ducts into the fibres* ; for when the ducts or branches pass into their least divisions, they then become those that actually compose the motive fibres.

407. *From the fibres into the coronary vessels, both arteries and veins.* It is well known that all muscles become indurated and pale during their constriction, or eject the blood from their motive fibres. The constriction of the heart is its systole, and during this, the blood cannot be expressed into the lacunæ, for the blood enclosed and highly compressed, prevents it. The blood cannot be driven in opposition to the resistance it meets, and to the sanguineous stream. Hence the whole of it passes into the superficial vessels, in which direction it finds an exit.

408. The facts ascertained upon experiment are alone sufficient to shew, that there is a communication of the fleshy ducts and lacunæ of the heart with the coronary vessels, both from the surface toward the interiors, and from the interiors toward the surface. *There is a communication from the surface towards the interiors.* “The open diverticula of the veins,” says Lancisi, “are conspicuous within the cavities of the heart, and the attentive anatomist will easily detect them, if, through the different mouths or emissaries of the coronary veins that open into the right auricle and into the top of the vena cava, he gently throw in either air or colored water, (for the trunks of the coronary veins have no valves) : when he will soon perceive the injection not only oozing into the right and left cavities, in the form of bubbles and little drops, as it were of sweat, but sometimes gushing out in little jets. . . . The water gently injected into . . . [one] orifice [of the coronary veins] by the syringe . . . was seen to pass under the columns themselves towards the apex of the left ventricle. In like manner, when air was thrown into another vein, . . . we immediately observed the columns in the left ventricle tremulous and vibrating, and bubbles rising in different parts. . . . We threw in liquids through the anterior



coronary veins also, and saw . . . the transverse column particularly, or the fleshy beam, bedewed with drops. So that I could no longer doubt the existence of an intimate communication between the coronary veins and the two ventricles" (n. 388, p. 367, 368). A variety of other experimental facts relating to the subject are stated by Vieussens and Verheyen (n. 395—397). *There is a communication from the interiors to the surface.* "It is to be observed," says Lancisi, "that the orifices of the diverticula, which are numerous in both auricles and ventricles, are protected by no valves, but open freely and nakedly; so that others as well as myself have readily injected liquids with a syringe through these foramina, which liquids were diffused through the substance of the heart, or rather through the veins, and when they could not escape in any other way, regurgitated through the same orifices. . . . That the blood alternately goes in and out, with a kind of ebb and flow, through the before-mentioned diverticula of the veins, seems to be proved by what we have observed in regard to the lips of these orifices. For these lips are not rough, uneven or edged, but always smooth and polished; making it probable, that the liquids smooth down the margins of these little mouths by their alternate passage to and fro, as it were by the chafing of a fine and delicate pumice" (n. 388, p. 368). I wish Ruysch had tried this passage with his injections. What now can be plainer than that the blood expressed from the lacunæ into the ducts, is forced into the motive fibres, and prompts and urges them to diastole or reciprocal action. For, 1. Orifices that spread into ramifications, visibly open in the lacunæ, or under the columns. 2. The first blood that comes is received under these coverings, and in these crypts, and when once received, cannot be wrung out into the larger artery; for when the heart is constricted, it is compressed directly towards these lacunæ whenever it is compressed toward the intermediate septum. 3. The blood of the common ventricle presses upon it, and the particular walls or columns, which are also muscular, likewise press upon it. 4. By the continual washing of the blood, the mouths, together with the ducts, are smoothed down, as if by the chafing of the finest pumice. 5. The blood injected into them, is diffused through the substance of the heart, in the same manner as any other liquor, according

to the experiments adduced. 6. Part of the blood also passes into the veins, and part of it regurgitates. 7. When the blood passes from these ducts into the veins, it does not pass from the so-called arteries into the veins, at least no experiment has shewn that it does; for the blood flows into the ventricles from the arteries and from the veins equally; it also flows from the ventricles into the arteries and veins equally; shewing that all these vessels are of one class and have one origin.

409. But before we leave this subject, which is of the greatest importance in the doctrine of the heart, let us, by induction from what we have stated, yet still with experience at our side, ascertain how the blood is carried downwards from the lacunæ, through these ducts into the muscular substance of the heart, and how it is carried downwards into the coronary vessels. One thing is evident, that there are ducts leading into the muscular substance of the heart, and which we shall call *Immissaries*; that there are also ducts leading from the muscular substance into the coronary vessels, and which we shall call *Emissaries*; and that there are ducts leading immediately from the lacunæ into the coronary vessels, and from these back into the lacunæ, and which we may call *Commissaries*. 1. With respect to the passages that import the blood, or the immissaries, that there are such, and that they are the identical fleshy ducts which lead from the ventricles to the substance of the heart, is clear from what we have already shewn (n. 404, 406). 2. That there are passages that export the blood, or emissaries, is evident from the same experimental facts; for since the blood cannot be forced back into the lacunæ of the heart, namely, during systole, it must necessarily be forced through the emissaries to the surface, or into the superficial vessels. I have sometimes, in following up the direction of the muscular planes with a careful eye, seen little ducts which universally, like the planes themselves, after leading toward the base or middle septum of the heart, have attached themselves to the two sets of coronary vessels: and besides these, I have seen other fistular passages terminating near some common vessel. The rest, which were twigs proceeding from these, and which terminated in the capillaries of the coronary vessels, it was not so easy to follow. "Since the muscular planes and fasciæ," says Lancisi, "are far more abundant in



the heart than in any other muscle, it is necessary that each line and curve thereof, each bundle, and each fibre, should be tracked by little arteries of its own" (n. 387, p. 364). 3. That there are communicating ducts, or commissaries, appears from this, that a passage is possible from the coronary vessels into the lacunæ of the ventricles, and from the lacunæ of the ventricles into the vessels (n. 408). "I am aware," says Lancisi, "that the most celebrated anatomists of the present day, and especially Thebesius, . . . have shewn that the passages and tubules that convey the blood from the larger coronary veins into the ventricles, assist these veins necessarily, either always, or when occasion requires" (n. 388, p. 367). I have likewise seen ducts opening especially from the upper lacunæ of the right ventricle, and in general leading down deeply to the wall of a single large coronary vessel, so that when a bristle was inserted, its progress terminated in the vessel itself.

410. Further; during the systole of the heart there is no other exit for the blood than through the large arteries, namely, the pulmonary artery and aorta, and at the same time through these fleshy ducts towards the muscular substance of the heart, and at the same time from the muscular substance into the superficial vessels; in a word, through all the immissaries and emissaries, but not through the commissaries. But when the heart returns to its diastole or expansion, these ducts are closed, and the others are opened; namely, the communicatory or commissary; so that by these means the blood can be driven freely from the coronary vessels into the ventricles, and back again. But let us proceed to particulars.

411. During the systole of the heart there is no other exit for the blood than through the large arteries, namely, the pulmonary artery and aorta.—This is an incontestible and well-known fact; for there are valves to prevent the blood from passing out of the ventricles into the auricles.

412. And at the same time through these fleshy ducts towards the muscular substance of the heart.—For these ducts are so many small and proper arteries of the heart, and have their own small and proper ventricles or chambers, which we have denominated lacunæ. Some of them are supplied with valves; to some a fleshy column itself serves the office of a valve; to

others the innermost membrane of the heart; while others have lacerti to constrict them. That they lead toward the substance of the heart, is a fact indicated by what we have already stated (n. 408); as also that they have in them little sphincters in lieu of valves, lest during systole they should divert the blood in any other direction than toward the motive fibres. "In the lesser branches of the coronaries," says Lancisi, which dip deeply into the muscular substance of the heart and auricles, . . . we find little sphincters and valves beautifully and abundantly distributed" (n. 387, p. 363). Again he says: "At the little mouths of the lesser and least arteries that are distributed through, and buried within, one or other of the muscular planes, we saw valves opposed, which in fact prevented the regress of the blood from the lesser arteries into the larger" (n. 387, p. 364). So that these passages appear to be constructed with such ingenuity and forethought, that the blood sent into the proper arteries of the heart and auricles, or into the immissaries, perpetually stimulates the motive fibre to receive it, and thus excites the entire muscle of the heart to its diastole and reciprocal systole; for otherwise the fibre of the heart would be destitute of its active and expanding force.

413. And at the same time from the muscular substance into the superficial vessels.—For the muscle, when emptied of its blood, cannot propel that blood in any other direction (n. 407); as we shall the better see when we come to treat of the systole and diastole of the coronary vessels.

414. In a word, through all the immissaries and emissaries, but not through the commissaries;—so that the effect of the systole, or of the heart when engaged in constriction, seems to be, that all the other passages are closed, and that an exit is opened, and the blood expressed, only into the general and proper arteries of the heart, and from these to its surface. For experiments have been made by injecting the superficial vessels or fleshy ducts in a flaccid heart, in which state the heart is as it were in its diastole; and in this case it is very clear that the passages are kept open. In speaking of his dissection of the heart of a mastiff, Lancisi says: "We happened to grasp the left ventricle in our hand, and to press strongly against the septum; and we saw very minute and slightly red drops of ichor issue



slowly from certain little mouths in different parts of the septum and its vicinity" (n. 388, p. 367). Hence we learn that the blood is expressed into the commissaries, and determined in the direction in which there is the least resistance; that is to say, into the now empty ventricle. Reason moreover leads to the same conclusion; for if at the time of the heart's systole, the anastomoses stood open so that the blood could be derived from the lacunæ into the superficial vessels equally as well as into the motive fibres, then the greatest part, if not the whole of it, would pass the motive fibres by, and be expelled with violence; while the cruder parts intermixed with the blood, as well as the recent ehyle, which could not be conveyed into the fine motive fibres, would clog the immissaries, and dull and extinguish the muscular forces. The texture of the heart, therefore, seems to be so framed, that as the motive fibres constrict, they draw apart the walls of the vessels leading to them, and press upon the others. This appears to coincide with the fact, of one species of vessels passing through the texture of the fibres, and of the other creeping along the strata.

415. *From the coronary vessels, either through two foramina into the aorta, or through one large foramen into the right auricle, or through several small foramina into the same.* Since therefore the blood is expressed from the lacunæ into the fleshy ducts, and from the fleshy ducts into the motive fibres (n. 406), and from the motive fibres into the coronary vessels (n. 407, &c.); and since the latter do not arise from the root of the aorta, but from the heart itself (n. 399—402); it follows, that the blood does not flow in any other direction than through all the beforementioned orifices, either in the aorta or in the auricles. To this cumulative experience we may add, that besides the common valves, or those that elose the orifices of the aorta, there are sometimes particular valves, of which Laneisi thus speaks: "The coronary arteries have no valves at their immissaries; although Thomas Bartholin, because he happened to meet with valves once or twice, (as I myself likewise have done,) presumes that they are to be found always" (n. 387, p. 363). Hence it appears that wherever these valves are to be found, the same law obtains with regard to the foramina of the aorta as with regard to the foramen in the right auricle; for this foramen is some-

times closed with a certain valve, and is sometimes open. On which subject Lancisi again says: "Although it [the valve which covers the larger orifice of the coronary vein] is for the most part single and solitary, and shields and defends either one or two together of the mouths of the veins, yet it is sometimes wanting entirely, the large orifice of the coronary vein lying quite naked and open. . . . And not only is one lunular or crescentic valve sometimes seen, but sometimes two, to correspond to the two orifices of the vein," &c. (n. 388, p. 366). Thus there is a perfect parallelism between the orifices of the right auricle and those of the aorta, that is to say, one has its valves as well as the other. Each of them may be destitute of valves, inasmuch as the passage leading thither is closed to each at the time of systole (n. 401. 3). This also follows as a consequence from the fact, that the so-called arteries are filled at the same time as the veins; for they come from a similar origin (n. 401); they proceed in a similar manner along the surface of the heart, and have no communication with each other; the right ventricle also expands and contracts at the same time as the left, &c.

416. But it may perhaps be objected, that in this case experience is self-contradictory; that, for instance, the blood does not pass from the smaller branches of the so-called arteries immediately into the larger, because little sphincters or rugæ seem to act as valves to obstruct the passage. "We carefully noted the skill of nature," says Lancisi, "in placing at the mouths of each of the larger coronary arteries, where they divided into the smaller, a kind of circular margin or border, and as it were a delicate sphincter" (n. 387, p. 364). And in another place he observes: "We find that water injected into the coronary arteries, and diffused through the substance of the heart, never runs back even when the heart is compressed" (*Ibid.*) This was the case not only in regard to the arteries but to the veins; for he says: "We seldom find valves in the larger trunks of the coronary veins, but always in the smaller branches, as we found to be usual in the arteries" (n. 388, p. 367). This however in no way invalidates or contradicts our position, for they are not valves, that are simply allocated, but little sphincters that constrict, and little rugæ that fold together, as soon as the blood attempts to pass from the smaller arteries and veins into the



empty vessels of the upper parts. For Lancisi says, "the innermost membrane runs into numerous rugæ, which in some measure perform the office of valves, and prevent the return of the blood into the aorta, as also does its reaction or resistance *a tergo*" (n. 387, p. 364). "On injecting mercury into the coronary artery, it was curious to see the larger branches become corrugated, and the smaller strangulated, as if by nervous threads" (*Ibid.*, p. 363, 364). Let us now mark the wonderful wisdom that nature has here exhibited, in that in the place of valves she has constructed delicate sphincters, and invested these minute canals with a lax membrane, that readily runs into corrugations, and produces a certain reactive tendency. For hence it is very evident, 1. That the blood cannot flow from a smaller vessel into a larger, before the larger be partly filled by the emissaries, and by the communicating branches at the surface; for were the blood to pass directly and rapidly from the smallest vessels to the larger, the whole of it would then be conveyed thither, and the smallest vessels would undergo complete collapse, and at length be obliterated; for the expansion and constriction of the heart near the apex [*juxta conum*] is greater than near the base. 2. It is thus provided, that the blood shall not flow from the smallest to the larger vessels before the larger are in a certain degree of expansion; and as often as they are in this state of expansion, the delicate sphincters are drawn open; for when the larger vessels are thus drawn open, the mouths we have spoken of are naturally opened; and at the same moment also the little rugæ are smoothed out, in order that there may be a transflux of the blood from one into the other. 3. Consequently an equation of the superficial blood of the heart, thus expanded and constricted as it is in different ways, cannot be obtained otherwise. 4. When the large and the smallest arteries are constricted, the passage through the sphincters and rugæ is closed; hence the blood is determined from the smaller into the smallest arteries. For this reason, during the diastole of the heart, the surface which is composed of the smallest arteries, reddens; but during the systole of the heart, it grows pale; the blood flowing freely from the smaller vessel into the larger. 5. Without this wise provision, the heart itself would perform too great a diastole, and would be expanded beyond its just

limits. Lest this should take place, it is provided, that a stop be put to the blood to prevent its flowing into the larger vessels, and to cause it to enter only into the smallest vessels of the fleshy surface, but no further; for which reason the heart is here compressed, lest the blood should pour forth still further. Such then appears to be the reason why, by the foregoing expedient, the communication between the small branches and trunks is closed; namely, (to recapitulate briefly what I have said,) that the surface of the heart, composed as it is of the smallest vessels, may not be deprived of its blood; and that the communication between the fleshy substance of the heart, and its surface, may not be intercepted; and that the proper cause may not be wanting to prescribe the limits to its expansion, and to incite it from diastole to systole. In the accomplishment of this object, the heart, like every other muscle, must redden during its diastole, and grow pale during its systole; the contrary of which would happen in case the blood met with no impediment, and flowed from the smallest into the larger vessels. The law, therefore, which obtains in the distribution of blood upon the surface, is similar to that which obtains in the substance of the heart itself, where there are sphincters and rugæ (n. 412). We may also observe, that the blood can always by means of a syringe be poured from the larger branches into the smaller, and from the smaller into the larger; this is sufficiently testified by the experience adduced in n. 408: so that by this singular expedient, the communication is modified solely for the sake of the uses and ends we have already indicated. But as we cannot have a clear idea of these subjects before the diastole and systole of the coronary vessels are explained, let us proceed to the consideration of this subject, after which we shall return to that of the present article.

417. *But the superfluous blood in the coronary vessels runs back into the lacunæ and ventricles.* That there is a passage from the vessels into the lacunæ of the heart, and from the lacunæ into the vessels, is proved by the experiments recorded by various authors, as by those of Lancisi (n. 388, 408), Vieussens (n. 396), Verheyen (n. 397), and numerous others, so that it would be needless to dwell longer upon this subject. This arrangement is for the sake of preserving or restoring the general



equation or equilibrium (n. 227) : and if from different contingent causes the blood should not be expelled in due proportion through the openings in the aorta or the auricle ; or if the heart should perform too great a spasmodic action, or remain in motion for too long a time ; or if the apex should be expanded more than the base, &c., then in these or similar cases the blood thrown into the coronaries would have a plentiful reflux ; without which the heart's motion would be so suspended that the organ would be in a state of tetanus, the vessels would be ruptured, action would be destitute of reaction, and the heart would perish prematurely, or before the rest of the body. For this reason, the commissaries or communicating ducts do not open unless the heart is in diastole (n. 410, 414), when the surface ejects its wave either into the aorta or into the auricle (n. 415).

418. *All these vessels depend entirely on the action of the heart.* The heart is the purveyor of the blood. This I think is clear from the statements preceding our induction. It is evident also from this circumstance, that when it expels the blood received, it first of all urges it into its lacunæ and diverticula, and this, before it sends even the smallest part of it into the large arteries, the pulmonary and the aorta. Thus, in case it is in want of blood, it appropriates to itself the blood destined for the lungs, and also that destined for the body in general ; for the life of the other parts of the body depends upon the life of the heart. Hence it is, that in the right ventricle there are so many particular chambers, for the blood flows into the right ventricle before it flows into the left, and this, too, with greater certainty ; so that the heart must be provided with its own blood, before the lungs and left ventricle are provided with theirs, and should due provision fail, the quantity required to supply the deficiency comes from the left ventricle, where there are only a few columns, lacunæ, and sanguiducts. The heart has also so disposed these chambers near its septum, that while it compresses itself, it acts upon all of them ; for the sides of the ventricle are as it were brought into collision near the septum : and this is the reason why the heart is the first organ that lives, and the last that dies.

419. The heart also is the motor of its own proper blood, or the general motion of the heart,—its expansion and constriction,

—is the cause of the motion, or expansion and constriction, of all the superficial vessels : for these vessels not only occupy, but constitute, the surface, since their ramifications pervade the minutest point ; and hence the heart is the cause of the expansion and constriction of the surface, and also of the vessels that constitute the surface, and this, too, especially for this reason, that they do not arise from the aorta, but from the heart, and its infinitely numerous points. There are likewise continuations not only of its motive fibres, but of the sanguiducts of its muscular substance ; and when these ducts are opened and constricted by the heart, like the aorta and the pulmonary artery on a great scale, these vessels are also continuations of the same stream of motion. There is no such thing, therefore, as a particular motion of any one of these vessels, for they have all a common or general motion, as also a perpetual intercommunication. This is confirmed by the fact, that the innermost membrane of every vessel is rugose, and thus dilatable according to the state of the expansion and constriction of the whole. The case is otherwise with regard to the arteries and veins of the body. Moreover, the so-called arteries cannot continue their motion into the so-called veins, for the two do not communicate. We may thus conclude that the heart acts upon its own proper vessels immediately ; but not mediately, and as it were reflexively, through its aorta ; a kind of action which is not possible to it.

420. *In the stream of whose motion both they, and the motive fibres, and fleshy ducts, as well as the lacunæ of the ventricles and auricles, are set and disposed.* This will most easily be shewn by a survey of the parts respectively. For instance, that the *lacunæ of the ventricles* are in this stream of motion, we have above pointed out, for they open about the septum of the ventricles, towards which the compression of the parietes tends. Hence the heart when grasped in the hand, seems to fold its winding caverns one into the other, and the impacted wave seems to be detained among its munitions and in its narrow inlets : but when relaxed, it in a similar manner is evolved and exfasciated. That the *fleshy ducts* are in this stream of motion, is evident ; for they open for the most part at the bottom of the lacunæ, and immediately enter the muscular substance, irrigating and stimulating every motive fibre. It is through these



fleshy ducts only that the blood is sent when the heart is in its systole ; hence, unless they were in the stream of motion, no fibre could be animated by the ingress of blood. Consequently, the *motive fibres* are also in this stream of motion, being collected and divided into fascicles, into particular and general layers ; so that all the larger and smaller cavities are opened or folded, according to the nature of their arrangement. Hence the *superficial vessels*, commonly called coronary, are also in the stream of the motion of the heart, for they depend upon it (n. 419).

If we diligently examine these coronary vessels in regard to their situation and course, they appear to be so disposed in the stream of the heart's motion, that as often as they are either filled, or to be filled, with blood, they are rendered more capacious in every dimension ; they are, for instance, drawn apart so as to be broader, and at the same time shortened, so as to make room for the blood, and *vice versâ*. The very trunks that run right and left, and crown the base, are all in the same manner situated in the stream of the motion of the base. The same observation applies to the trunks and branches that run along the division of the septum, for they pass to the right ventricle ; so that while the latter is expanded, the former are drawn apart breadthwise, and at the same time relaxed ; for the production of which effect, they are frequently attached by a tendon of a peculiar kind. The other vessels, which proceed from these perpendicular branches, as well as from the trunks, direct their course in accordance with the same stream of motion. This appears to be the reason why the veins everywhere follow the course of the arteries. But I am here speaking of those vessels that increase from a smaller to a larger dimension, for there are also others that serve only for the purposes of communication, and these wind about in different directions. The manner in which these vessels follow the stream of motion, cannot be shewn better than by Ruysch's two figures, referred to in n. 393. It is there seen that from each of the trunks, shortly after their origin, a considerable branch is reflected, which runs over against the root or commencement of the aorta, below like a subtense, and gives off another branch, which descends nearly along the septum on the left side of the heart, and divides into

two twigs, that unite with the former coronary artery. This subtense so surrounds the aorta, that it is opened and constricted precisely as the aorta swells or subsides. But the Figure itself will give a better idea than any description. We must here add, while upon this subject, that from the subtending arc offsets rise to the aorta itself, although not to any great distance. These I think do not spring from the coronary vessels, according to the common opinion, but from the mammaries, which enter the surface of the aorta not far from this spot, and the little veins of which discharge themselves into the coronaries, into which likewise they pass at right angles.

421. *From which it follows, that all the vessels that occupy the surface of the heart are venous, the arteries corresponding to which are in the substance of the heart.* That the coronary vessels are the proper veins of the heart, follows from what we have already stated. For they all belong to the same family, and spring from the lacunæ of the heart; they likewise proceed upon the surface, and do not communicate with each other; they increase from the smallest twigs to the larger, and the blood flows into all simultaneously; they simultaneously commence and terminate their diastole and systole; they do not possess any membrane common to the arteries or similar to it, but are rugose internally and full of folds; hence they cannot propel the sanguineous stream from one point to another with any pulsatory and undulatory motion (n. 192—197). They meet together from innumerable sources, and thus undergo impletion (n. 190). They are all passive, and hence are sent out to the surface (n. 419). Therefore they are veins.

422. But the fleshy ducts that lead from the crypts of the ventricles and auricles into the muscular substance of the heart, are no other than the arteries of these veins; they are so many diminutive aortas, or as it were pulmonary arteries, inasmuch as they are distinguished by their own ventricles, septa, and occasionally valves; they arise immediately from the general cavity of the heart; they observe the same systole; while their nature and their integuments are altogether different from those of the vessels that occupy the surface. They gradually decrease in size, and are divided in their course from larger branches or ducts into smaller, till at length they become extremely minute



vessels, which constitute the several motive fibres in the same manner as do the arteries in every other muscle of the body. Hence these ducts are the proper arteries of the heart. These arteries occupy the interiors, for the heart leads them into its recesses, and forms its substance of them; so that in all respects it is a muscle, and the strength and life of its body (n. 231).

423. *Such then being the origin of the coronary blood, it follows, that the superficial vessels, commonly called coronary, perform their diastole when the heart performs systole: and in like manner that the superficial vessels of the auricles perform their diastole when the auricles perform systole; and vice versâ.* For this is a link in the chain of causes, and another element of the same series. For if all the vessels depend entirely on the action of the heart (n. 418, 419), and lie in the stream of its motion (n. 420), are veins (n. 421), and are constricted simultaneously, it follows, that they can be enlarged only when the heart undergoes its systole and compresses its belly, and *vice versâ*. The experience of Lancisi confirms this view of the subject. "In the vivisection of mastiffs," says he, "... we have seen the coronary artery pulsating at the same time with the aorta, both being expanded and constricted simultaneously; and in like manner when punctured, the jet of blood from both, and the interval between the jets, was synchronous. But in sheep, which have the immissaries of the coronary arteries placed under the valves, we saw the aorta begin its diastole somewhat before the coronary artery, but both completed the diastole at the same time" (n. 387, *ad fin.*) And Morgagni seems tacitly to refute the contrary opinion, where he says: "When they [the orifices of the coronary arteries] lie entirely below it [the border of the valves], and are consequently blocked up at every systole by the valves, (which in fact are pressed closely against them by the blood rushing from the heart,) it appears necessarily to follow, that if afterwards the artery contracts, and pressing back the blood, displaces and unfolds the valves, the blood may be then admitted into the above orifices. And in this case we must assent to the learned Boerhaave, where he says, that 'the coronary arteries undergo diastole while the other arteries of the body are performing systole.' But although this, as I have stated it, appears

to be the case at first sight, yet perhaps on closer consideration it will scarcely seem probable, that in a matter of such great moment, so great a variety should exist in different individuals" (n. 394).

424. A similar action prevails in the vessels of the auricles, all of which depend on the motion of their proper auricle, as the others depend on that of their proper ventricle; hence the latter perform their diastole when the vessels of the auricle perform their systole. But the difference between the motion of those that pertain to the ventricles and those that pertain to the auricles, is not easily understood, unless we are well acquainted with the reciprocation of the motions, and the influx of blood from the auricles into the ventricles, to which the coronaries accommodate themselves. Of this motion we shall speak in the next chapter.

425. One of Lancisi's experiments is the only thing that at first sight appears to militate against this view, and which experiment is thus described: "If we take the heart of a man, dog, or sheep, we shall find it generally relaxed and flaccid, or as it were in a state of diastole, with the coronary arteries and veins very large and conspicuous. And if we slightly moisten it on the outside with boiling water, and inject it with the same, we shall immediately see it pass from diastole into strong systole, and the external coronary vessels become smaller and in a manner obliterated" (n. 388, *ad fin.*) Except that this fact is in contrariety with another previously adduced (n. 423), namely, the one observed in the living heart, it follows also that in the present case, just what we have described, obtains; for when the heart is emptied of blood, and the immissaries and emissaries are likewise empty, the coronary blood necessarily flows back into the open emissaries, and the blood which is in the motive fibres is expressed into the immissaries; hence when the ducts are distended a contrary effect is produced to that which takes place when they are emptied. It is for this reason that the coronary arteries and veins are seen to be so large in the flaccid heart, which is as it were in a state of diastole; for there is no swelling of the ventricle when emptied of blood, or collapsed: hence room is rather afforded for the superficial vessels to fill instead of to empty themselves, for the condition of their



emptying is the swelling of the heart occasioned by the blood, giving a general expansion to the ventricles, and to the motive fibres of its substance in every particular.

426. It is worthy of observation, that the cardiac nerves that penetrate into the muscular fibre, are not the same as those that beset the coronary vessels, but are perfectly distinct in their origin and progress. Those that beset the coronaries of the heart, and those that beset the coronaries of the auricles, come immediately from the trunks or ganglia, and enter into the heart by a different passage. But those that bind the motive fibres, come from the great and small cardiac plexus, and pass down from the belts or bands that surround the orifices of the veins and heart. This subject will be explained in the next chapter, when we speak of the Motion of the Heart. In order that when the nervous fibre constricts the motive or muscular fibre of the heart, the coronary vessels may not be subjected to a similar constriction, in which case the systole of the coronaries would coincide with the systole of the heart, the nerves introduced are derived at once from a different origin (n. 501).

427. Hence it follows, 1. That all the arteries and veins, both those common to the body, and those proper to the ventricles, namely, the aorta, the pulmonary artery, the two auricles, and the fleshy ducts or immissaries and emissaries, as well as all the coronary vessels, perform their diastole at the time when the heart or the two ventricles undergo their systole. 2. All the arteries and veins, both those which are common, and those which are proper to the heart, together with the communicating vessels or commissaries, perform their systole at the time when the heart itself, namely the two ventricles, are performing their diastole. 3. At the time of systole, all the outlets from the fleshy ducts to the coronary vessels, and from the coronary vessels to the aorta and right auricle, are closed; and those only are open that lead to the motive fibres, such as the immissaries and emissaries. A similar arrangement commonly takes place in the other muscles of the body, of which the great cardiac muscle, or the heart itself, is the type and exemplar. When these muscles are constricted, no blood passes through them into the veins, except by communicatory branches, such as we have here denominated commissaries.

428. *But as many anomalies occur in the auricles, and in the right auricle particularly, so, in order that the auricular blood may find an outlet in all cases and under every circumstance, a number of orifices are provided, through which this blood can be thrown out, suitably to all diversities of state.* There are both general and particular anomalies and varieties in the motion of the heart, as is very evident from the pulse. Thus this motion, of diastole and systole, is more or less equal or unequal, quick or slow, high or low, strong or weak. It is of one kind if the fibre be strongly inspired; of another if the blood contain any crudity, any molecules of bile, calculus, or glairy substance, to clog or irritate the fibre; of another kind if the quantity of blood in the left ventricle does not correspond with that in the right, as where the breath is for a long time suspended, or the passages for the transflux of the blood through the muscles are closed, or where the artery offers a resistance from having acquired too great a degree of general repressive power; of another kind if the mouths that lead into the fleshy substance of the heart are overlaid with any viscid substance; of another kind if a portion of its muscle grows pale, tendinous, or osseous, or if one portion, or one column or valve has more strength and vitality than its associate. This is particularly the case with regard to the right auricle, which receives and commingles the blood on its first arrival, and which is so constructed, that it can beat and palpitate twice or thrice in general and in particular without its associate ventricles. To say nothing of the universal variety in hearts, and especially in human hearts, no two of which are ever exactly alike, either at the beginning or throughout life. Each heart also varies according to contingent circumstances, and assumes an appearance proper to itself, although not equally natural to any other heart. For these reasons, the orifices of the [coronaries in the] aorta lie sometimes below the border of the nest-like valve, sometimes half above it; sometimes they have a different relation to each other; sometimes there are two of them, sometimes three, and at other times there is only one. So, too, the coronary opening in the right auricle, or rather in the venous sinus, is sometimes single, sometimes double, seldom triple, and is either covered with a valve of different shapes in different persons, or else is left exposed. "Nature is so variable



and inconstant," says Lancisi, "in locating the mouths of the coronary arteries, that a few dissections only, especially if made in the human subject, are sufficient to present us with many varieties (n. 387, p. 365). We found nature often variable and inconstant with respect to the immissaries of the coronary arteries; we have now to observe that the same may be said of the emissaries of the coronary veins, which in fact open in the heart without following any ascertained law. Thus although they generally open within the sinus of the right auricle, near the cava, by two mouths, one superior, and the other inferior, yet sometimes they open only by one orifice, and this of large size, which immediately after separates into two; and not seldom they open by three orifices, which are always found proportionally somewhat smaller" (n. 388, p. 366).

429. And not only in the general mouths now spoken of, but also in the other oscilla that exist in the auricles, there is very frequently great variety. Thus in the right auricle there are several oscilla or little mouths; there are two or three, for instance, of large size, and which divide among them the blood about to flow out, and dispense it to suit the state. Besides these there are innumerable others not so easily seen; there are others again in the vena cava, which is continuous with the sinus of the auricle; there are others in the left auricle, and which may be best seen by a reference to Verheyen, *Corp. Hum. Anat.*, tab. xx., fig. 2. And these vessels, whether ventricular or auricular, after their diverse and ambiguous course, discharge themselves sometimes through one orifice, sometimes through another, and so distribute the streams among them, that when the blood cannot escape by one orifice, it escapes by the other, and thus finds a receptacle under every contingency. "I . . . remarked," says Verheyen, "that the vein commonly known as the coronary . . . is almost entirely spent in branches that run to the apex of the heart; . . . so that only a small branch runs on from it to the right auricle, and as it begins to approach the auricle, is again enlarged by the accession of fresh twigs, until at length it divides into branches, which after distributing twigs through the substance of the auricle, open . . . by a variety of orifices into its cavity (n. 397, p. 376). [Besides the great orifice] I also found two other venous orifices in the cavity of the

same auricle : these were the orifices of offsets of the above vein, but which offsets I could not well see on account of the sulcated character of the auricle," &c. (*Ibid.*, p. 375). The reader may see in Verheyen's plates (*Op. Cit.*, tab. xxi., fig. 3.), that little passages open into the vena cava ; for it is from this vein that the motion of the auricle begins : in which motion many remarkable anomalies may be detected, as will be shewn by experimental evidence in the next chapter.

430. Since therefore there are so many oscula or little mouths, into which the sanguineous fluid pours in order to discharge itself, so many fountains in the ventricles and auricles, and so many causes (n. 428) that obstruct and alter them, it is no wonder that the coronary vessels themselves, as they proceed from their origins to their terminations, should be liable to a similar and more extensive variety ; for the intermediates necessarily accommodate themselves to the condition and direction of the extremes (n. 227), and this to such a degree, that the coronary blood is never conveyed by the same channels in one heart as in another ; so great indeed is the variety, that were the anatomist to attempt to exhaust it, he must enumerate every individual heart. The membranous surface of the heart is itself composed of innumerable minute vessels, which are expanded when a sufficient cause demands ; and as the motion is determined to one or the other quarter, so the sanguineous stream is directed thither, and passages and outlets are constructed. This is the reason why the injection of wax by Ruysch has detected so many channels, and why one person from examining one heart will confirm the existence of a certain channel, while another examining a different heart will doubt or deny it. The cause of these variations it is not impossible to explore, for since all the superficial vessels, all the motive fibres, fleshy ducts and lacunæ of the ventricles and auricles, are disposed in the stream of the heart's motion (n. 420), and varieties frequently arise from the causes we have enumerated (n. 428), it follows, that if the series of visible effects be well examined and considered, the causes and reasons will be seen involved in the series, and be capable of being easily evolved, if a person of sound judgment, cultivated by experience, enter upon the examination.

431. *If we compare the origins of the coronary vessels with*



*the outlets of the same, it will be evident that the blood of the right side of the heart is transferred immediately into the aorta, and the blood of the left side of the heart into the right auricle; much as was the case in foetal life by means of the foramen ovale and ductus arteriosus; shewing that the coronary vessels and their mouths, relatively to the determinations of the quantity of blood running through them, are substituted in place of the foramen ovale and ductus arteriosus; the channel and mode of circulation only being changed.* To see to advantage the amazing hydraulic skill of nature, as exhibited on the surface of the heart, we must trace the course of these rivulets, one by one, in such a manner that the mind may keep close to the object of investigation, otherwise the eye, as it labors in following out the details, will find itself obscured as it were by cataract. But since in these respects there is so great a diversity in hearts, it is better for the mind to keep fixed in its universal notion, than to waste itself among a variety of particulars. We cannot do better than study Ruysch's two plates (n. 393), where this coronary circuit is graphically represented; and frequently read those authors who have pointed out by the process of injection the outlets and origins of these vessels. But since it is generally supposed that the so-called arteries terminate in the substance of the heart, when nevertheless this is their beginning and not their termination, it is necessary, in considering the facts ascertained by experiment, and which we have so frequently cited, that the reader represent to his mind the statements of authors in an inverse order; that is to say, he must contemplate the heads of the vessels as in their smallest branches, and the ends as in the largest, or where the various large orifices of which we have spoken, open into the aorta or into the auricle.

432. But before we compare the circulation of the blood through the coronary vessels with its circulation through the foramen ovale and ductus arteriosus, it will be necessary to examine all the general varieties of circulation which the coronary blood observes in its passage from the auricles or ventricles to its mouths or diversified outlets. For the blood is imbibed immediately from the right auricle, and is immediately refunded from this auricle through one or other of these orifices; or else it is imbibed from the right ventricle, and sent back into the

right auricle, in order to flow through some foramen belonging to this auricle ; or else it is conveyed from the right auricle to the left, or from the right ventricle to the left auricle, in order that it may there find a passage through some foramen ; or else that being derived into the so-called arteries, it may escape through the mouths of the aorta ; or else that when received from the left auricle, it may be conveyed by shorter passages into the aorta, or be carried back into the right auricle ; or else be driven from the left ventricle into the left auricle ; or else along this passage into the aorta, or again into the right auricle. But in order to have a distinct idea of all these varieties, it will be requisite to distribute these vessels into the following classes : namely, *refundent*, *retorquent*, *anticipant*, *transferent*, and *retroferent*.

433. The *refundent vessels* are those whose blood, received from the fleshy ducts or arteries of the right auricle, circulates through the auricle, and in a short time after is refunded into the auricle. All these vessels are called veins, and their blood performs the shortest circuit of any, and immediately flows through some large foramen belonging to its auricle, into the common cavity, in order to be passed through the lungs. Of these vessels Lancisi says : "Those coronary veins that come from the fibres of the auricles, are shorter than those that come from the muscular texture of the ventricles, so that by the same law by which the blood runs through the coronary arteries into the parietes of the auricles, sooner than into the parietes of the ventricles, it returns through the veins from the auricles sooner than from the ventricles" (n. 388, p. 366, 367).

There are *refundent vessels belonging also to the left auricle*, and which arise from the fleshy ducts, and empty themselves perhaps into the same auricle. In this auricle there are certain small foramina, and Verheyen has noticed one of somewhat large size, (*Corp. Hum. Anat.*, tab. xx., fig. 2 :) although I consider this appearance to be rare, because this blood is derived for the most part into the so-called arteries, and into the aorta. The moment it is refunded into the auricle, it is transported through the lungs, and again mixes with the blood about to flow into the left ventricle, in order that, with the rest of the blood, it may be expressed into the aorta.

434. The *retorquent vessels* are those that arise from the la-



cunæ and fleshy ducts *of the right ventricle*, and having gained the surface, conduct the blood back into the right auricle, in order that it may escape through some one of its foramina. These vessels are numerous, and are called veins, and their blood twice visits the auricle, and twice the ventricle, before it is conveyed through the lungs. Respecting these vessels we have the following experiments by Lancisi: "We selected also a third posterior vein," says he, "the liquor thrown in through which, came out by certain most minute roundish openings existing in the internal tunic of the right ventricle, towards its apex and middle septum. . . . We threw in liquids through the anterior coronary veins also, and saw the right ventricle evidently moistened, and the transverse column particularly, or the fleshy beam, bedewed with drops (n. 388, p. 368). The third trunk we found occupying the anterior surface of the heart, and bringing back the blood from the bundles of fibres belonging to the right ventricle." (*Ibid.*, p. 366.) And Verheyen observes: "I threw in water through the grand branch [of the coronary vein], and it readily found its way to the cavity of the right ventricle, and escaped by the orifice of the divided vena cava. . . . It escaped so largely from the orifices on the inside of the ventricle, that there was no seeing the places from which it came. . . . The vein commonly known as the coronary, (which opens . . . near the foramen ovale and the cicatrix thereof,) is almost entirely spent in branches that run to the apex of the heart, (or if we may so speak, is constituted of branches proceeding from the apex)" (n. 397).

435. Whether or not there are also *retorquent vessels belonging to the left ventricle*, or vessels that arise from this ventricle, and then turn back to the left auricle, in order there to discharge themselves, is a matter of doubt, for they all empty themselves into some coronary vessel that leads either into the aorta or into the right auricle. See n. 433. The retorquent vessels therefore of the left ventricle, are such as issue from the lacunæ of this ventricle, and after crossing the surface, empty themselves into the aorta. They are commonly called arteries, and are found by injection to open into some of the so-called coronary arteries, from which some of these run through vessels of this class into that ventricle. Verheyen says: "He [Vieussens]

... made other injections with the same tincture, at one time into the right, at another time into the left coronary artery, and he saw the liquid pass respectively into the right or left ventricle, not omitting also the right auricle" (n. 396). Lancisi also observes: "When we injected mercury through the coronary arteries of the heart of a dog, we not only found the larger, smaller and capillary branches that ramified over the external surface filled with the injection; but in dissecting the ventricles, and the left especially, we saw the lacerti, columns and cords of the internal surface, beautifully distended by the mercury, so that they shone like silver, and presented the appearance of transparent tubules, which although perfectly sound, yet sweated all over with minute drops of mercury, and when cut into, let out the mercury in large quantities" (n. 388, p. 368, 369).

436. The *anticipant vessels* are more particularly the vessels of the left auricle; those, I mean, which arise from its muscular substance, and immediately pour the blood through the two foramina into the aorta, and preoccupy this vessel, inasmuch as this blood is not first carried into the left ventricle. Ruysch calls these vessels, the auricular arteries of the heart. He says that no one has "delineated the arteries that spread their innumerable twigs through the auricles: although these arteries, termed by me the auricular arteries of the heart, proceed from the coronary artery on both sides, and are distributed through the auricles in all directions" (n. 392). The vast number of these vessels, and the manner in which they flow into a certain subtense (n. 393), and indeed into the coronary trunk itself, and so into the aorta, cannot be seen to better advantage than in Ruysch's plates. On this subject Verheyen observes, that Vieussens "injected tincture of saffron . . . into the left coronary artery. A portion of this tincture was without violence soon made to pass through the branches of the coronary artery into the entire substance of the left auricle, as shewn by its inflation, tension, and yellow color: and from the substance of this auricle the tincture fell into its cavity, and so into the pulmonary vein and left ventricle, without a drop passing into the right ventricle" (n. 396).

437. The *transferent vessels* are those that convey the blood



*from the right ventricle* into the coronary arteries, and so into the aorta. These arteries are numerous, and convey the blood immediately into the aorta, without its passing through the lungs. They may be shewn by injections (n. 435) : and thus it is evident, that more arteries arise from the sources on the right side of the heart than from those on the left, and that after passing the muscular layers, they come everywhere to the surface. Which indeed is clear from the course of these so-called arteries, as given in Ruysch's plates ; although not so clear as from the injection of tinctures, which run promiscuously into both ventricles. Lancisi says, "If mercury be injected into the arteries of the heart in a healthy state, it is seen to pass through the pores and minutest openings of the ventricles, but it does not so plainly issue by little jets as if thrown in through one of the trunks of the coronary veins" (n. 388, p. 367).

438. There are likewise *transferent vessels of the right auricle*, which carry the blood into the aorta by a shorter passage, as is clear from Ruysch's plate ; for several arteries run from the right auricle into the coronary subtense and trunk (n. 436).

439. The *retroferent vessels* are those that carry back the blood *from the left ventricle into the right auricle*, and are commonly called veins, deriving this name from their outlet in the auricle ; nevertheless they arise from both sinuses of the heart : but we are here speaking of those only that arise from the left sinus. "The open diverticula of the veins," says Lancisi, "are conspicuous within the cavities of the heart, and the attentive anatomist will easily detect them, if, through the different mouths or emissaries of the coronary veins that open into the right auricle and into the top of the vena cava, he gently throw in either air or colored water, (for the trunks of the coronary veins have no valves) : when he will soon perceive the injection not only oozing into the right and left cavities, in the form of bubbles and little drops, as it were of sweat, but sometimes gushing out in little jets. . . . We selected . . . the lesser mouth of a coronary vein. . . . The water gently injected into this orifice by the syringe, much to our admiration was seen to pass under the columns themselves towards the apex of the left ven-

tricle. In like manner, when air was thrown into another vein occupying the external and posterior part of the heart, we immediately observed the columns in the left ventricle tremulous and vibrating, and bubbles rising in different parts. . . . So that I could no longer doubt the existence of an intimate communication between the coronary veins and the two ventricles" (n. 388, p. 367, 368). Verheyen says: "I . . . selected another [vein] belonging rather to the left ventricle. . . . But whether air or water was thrown in, I could not observe more than four orifices out of which either issued" (n. 397). The blood of the veins runs more readily indeed into the right ventricle—in which case there are retorquent vessels bringing the blood back (n. 434),—both because there are more lacunæ and springs in this ventricle than in the left, and because there is a densely muscular wall, which has to be crossed frequently by several windings, and which in a flaccid heart are very complicated.

440. There are also *retroferent vessels*, bringing back the blood *from the left auricle into the right*. This Verheyen proves by experiment, in opposition to the opinion of Vieussens, and concludes that "the auricles of the heart are certainly not destitute of veins," and that "a vast number of vessels open directly into the cavities of the ventricles and auricles, . . . and indeed many more into the right ventricle and auricle than into the left" (n. 397). This translation of the blood is shorter than that from the left ventricle, and takes place by a kind of anticipation.

441. From these statements we may learn the gyres that the proper blood of the heart performs. 1. There is a gyre in which the blood visits the right auricle twice, and the right ventricle twice, before it passes through the lungs. This gyre is made by the blood carried through the refundent vessels of the right auricle (n. 433), and the retorquent vessels (n. 434). 2. There is a gyre in which the blood is conveyed immediately into the aorta, without first passing through the lungs, as in the case of the vessels leading from the right ventricle (n. 437), which are called transferent, and in those leading from the right auricle (n. 438). 3. There is a gyre in which the blood passes twice through the lungs, and twice enters the left auricle and left ventricle, as in the case of the retroferent vessels (n. 439, 440). 4. There is a gyre in which the blood, in passing through the



lungs, does not first run to the left ventricle, but is conveyed immediately into the aorta, by the vessels called anticipant, (n. 436). 5. There is a gyre in which the blood is conveyed from the left ventricle into the aorta by the coronary channel, through the vessels called the retorquents of the left ventricle (n. 435). We may now then see what vessels, or what orifices of vessels, succeed to the office of the foramen ovale, the direction and mode of the circulation alone being changed.

442. There are no other vessels but those above denominated transferent (n. 437, 438), that transfer the blood either from the right auricle, or from the right ventricle, immediately into the aorta, without passing through the lungs. All those vessels are commonly called arteries, and are several in number. They are open and pervious, so that when water or air is injected into them, although in the opposite direction [to that taken by their blood], it issues out in jets and torrents. This passage succeeds therefore to the place of the former, but especially that from the right ventricle, where there are so many lacunæ and fleshy ducts to take up the blood, and absorb it on its first arrival. In virtue of this arrangement, no larger portion can be conveyed into the lungs, than remains (when the ventricle is filled) in the satiated proper vessels of the heart, and in the satiated coronaries. The foramen ovale of embryos thus appears to be as it were open in some measure in every adult, although a precaution is observed, lest the stream that is immediately determined by this passage into the aorta, should intermix with the stream that is turned back again into the right auricle; for which reason the coronary artery nowhere communicates with the vein, as Winslow has likewise remarked. "All the coronary veins," says he, "and their ramifications intercommunicate, so that if we blow through a small hole made in any one of them, . . . we observe that the air swells all the vessels" (n. 391). And Verheyen says: "That [according to the conclusion of Vieussens] these veins do not communicate immediately with the superficial arteries, . . . as do the veins in the liver, spleen, and some other parts" (n. 396). Hence the mouth of the coronary vein is placed in the venous sinus, close to the foramen ovale, but is closed by a valve that prevents the ingress of blood from the auricle, while the foramen ovale is in the contrary way

closed by a valve that prevents the egress of blood from the left auricle; and hence, in order to prevent the venous blood that is to be transferred into the aorta, from being carried back, these vessels keep distinct from each other, and do not inter-communicate.

443. It is evident, moreover, that by means of the coronary vessels, there is a communication of the left auricle or ventricle with the right auricle, just as if the foramen ovale opened from the left to the right, according to the statement of Mery (n. 321, 356—358). These vessels are called retroferent (n. 439, 440), because they carry the blood back from the left ventricle or sinus into the right, and are in general termed veins; and in those cases in which we find a great abundance of them, we may infer, that this passage for the reflux of the blood is substituted in the place of that through the foramen ovale, when the valve is closed so as to stop the passage. Were this passage, however, entirely intercepted, and any of those causes were in action, of which we spoke above (n. 356—358), then it seems that a force could be exercised against the barrier of the foramen ovale, and a way of regress opened.

444. Again it is evident that the coronary vessels called transferent, not only succeed in place of the foramen ovale, but also in that of the ductus arteriosus; for the blood conveyed from the right ventricle into the aorta through the so-called arteries, aims at an immediate transflux from the pulmonary artery into the aorta; for this reason the relation between the two, that is, between the foramen ovale and ductus arteriosus, is represented in the coronary vessels.

445. From the coronary vessels then we must derive the reason why the foramen ovale is closed after birth; for when no transit can be effected along one passage, it must be effected along another, or along the one that presents the least resistance. In natural history we frequently find mention of those whose bodies, after being for some time under water, have been found, on being taken out, to be lurid, inflated, struck with a mortal chill, exhibiting the very image of death, and for a long period giving no sign of respiration or life; who when laid out upon a table have manifested only a feeble pulsation in the cervical artery, yet when submitted to warm treatment, and made



to disgorge the water they had taken in, they have again begun to shew symptoms of motion in their limbs, again opened their eyes, and recovered the play of the lungs, after their case had been considered hopeless. We likewise find mention of those who in consequence of suffocation, or some kind of obstruction in the gullet, or bronchia, had appeared beyond a doubt to be dead, nay, have even been carried to their graves, yet after their interment have risen again, and lived a posthumous life among the inhabitants of the world. We have likewise found mention of those who for several hours have walked at the bottom of some lake, surrounded with water as with their own natural atmosphere, and who yet have survived for a considerable time. Of others also we have found mention, who without any diving bell, have delved into the water for the sake of searching out the treasures of the deep, and have emerged with faces glowing with life, and with hands laden with the spoils of the ocean ; to say nothing of cases of swooning, syncope, and asphyxia. Need I refer also to certain species of animals, which contract a rigidity of body from their inhumation as it were during the winter, and after their sepulchral life are as often resuscitated at the return of the vernal or summer beam. Now, in these cases the passages being closed that lead from the right ventricle of the heart to the lungs, the lives of these various beings could never thus be restored, without producing a ruptured state of the præcordia, unless a way were open, through the foramen ovale, from the right to the left side of the heart, and so into the aorta, or unless there were a passage open instead through the coronary veins. This remark is more especially true, whenever from the urgency of the case, beside the passages which are open, others which had been obliterated are again restored, and new ones are formed. Nothing indeed is more common than this in the skin, the membranes and viscera, in the uterus and genital members, and in all kinds of tumors and inflammations.

446. *And this, in order that the superfluous quantity of arterial, or the superfluous quantity of venous blood, in this place of concourse, may not injure or destroy the natural state of the kingdom, subject as it is to such frequent mutations.* Since the transferent coronary vessels perform in some measure the part of the foramen ovale and ductus arteriosus, (both of which are now

closed,) it follows that they are kept open, or are opened wider in time, by the same causes as the foramen ovale and ductus arteriosus (n. 355). It is a general object here to prevent the natural state of the kingdom from going to ruin or destruction; for no member of the body sustains more severe shocks than the heart; on the one side from all the venous blood, which urges, and on the other from all the arterial blood, which re-urges. The heart is thus placed between two forces, active and reactive, and is adapted to equipoise the two. This it could not do, unless its superficial vessels took some part in producing the equilibration; and since these vessels are proper to the heart, their performance of this office is the same with its performance by the heart itself. The causes of the superfluous quantity of arterial or venous blood, or what is the same thing, the causes of the change of the general equilibrium of pressure, are either internal or external. The *internal* causes are all those that act upon the fibres from within, such as all the affections and changes of state of the brains, of which we have frequently spoken above (n. 355—358), and these are called the affections of the mind,\* for the fibre puts on the mind [*animus*] of its brain, and urges the blood either into the veins, or into the arteries, as is well known in cases of anger, daring, fear. The *external* causes are all those that act upon the fibres of the vessels from without, such as those of the blood itself, its heat, and viscosity; acrid, pungent, styptic serosity; fibrous concretion, calculus, polypus, and several other things, which are diseases of the body, and which we have spoken of in those parts of the work to which we have just alluded. The equilibrium of general pressure, therefore, undergoes a change arising from both these causes. This danger, however, is obviated by the transflux of the blood through the coronary vessels, without which, both systems would fall to ruin, since there would be no possibility of balancing the fluctuations, and restoring the declining equilibrium. Neither is the quantity small that passes through these vessels, as is evident from their orifices; for the great cardiac muscle grows pale, and projects the blood, at every stroke of the pulse.

447. But the case is different in embryos, which lie softly in

\* *Pathemata animi.*



the womb, and pass their little day in a placid and tranquil state, before they are excluded into the atmospheric world; they are profoundly ignorant of what it is for the internal cause to act in opposition to the external, and the external to excite the assent of the internal; they are profoundly ignorant of what it is for the rational mind to act in opposition to the animal mind, or the latter in opposition to the former; or for the fibre in the body to act in opposition to the blood, or the blood in opposition to the fibre: for all things grow with the utmost concord, nor does one interrupt or molest another. The brains and heart live and move in unanimity, and hence at this period the foramen ovale lies open, for receiving the entire stream of blood that ascends from the body through the cava; this blood the left ventricle transfers to the brains, and the brains, in their turn, to the body. The case however is altered, as soon as this innocent, most harmonious, and Astræan age is succeeded by a different or extra-uterine existence; that is to say, as soon as the brain and the body begin to act each as its own distinct and proper cause; when the muscular fibre begins to be excited against the blood, and the blood against the muscular fibre; nay, when it begins to exercise a control over the first beginnings of the fibres; in fine, whenever the internal cause is in conflict with the external. Then a superfluous quantity of arterial or of venous blood may beset both sides of the heart, and may oppress it to such a degree as to effect the destruction both of the heart and of the whole animal economy;—dangers which are provided against by the diversified modes of transflux through the coronary vessels.

448. *Hence it is clear, that neither the motion of the heart, nor the circulation of the blood, can subsist for any length of time, unless the peculiar vessels of the heart that discharge the blood into the aorta, and those that discharge it into the right auricle, pursue a perfectly distinct course, and have no communication with each other. Were they conjoined, the same effect would ensue as if the septum between the ventricles were perforated.* We have shewn above that the coronary arteries and veins, so called, have no communication with each other (401. 7.; 442), and that all the arteries are so mutually continuous, that a fluid in-

jected into one distends all the rest. Hence it is evident that there are only two general determinations of the blood, that is to say, either into the aorta, or into the right sinus; and that the particular determinations of which we have spoken (432—441), are not so distinctly discriminated from each other. But our proposition is, that if the two general directions met by anastomoses, either in the substance of the heart, or on its surface, the motion of the heart could not long continue; nor consequently the circulation of the blood; for the effect would be the same as if the septum of the ventricles were perforated, according to the opinion of the ancients. In this case the blood proper to the heart would instantly precipitate itself, either all into the right auricle, or all into the aorta, according to the first impetus it received, and in the direction in which it met with the least degree of resistance. Thus when the commissaries were expanded, the muscular fibre would be deprived of its blood, and the passages being dilated, the pulmonary artery, or the lungs, would also be deprived of their blood. There would be no reacting force on the surface of the heart to prescribe limits to its extension, nor any outward cause to compel the heart to reciprocate its motion. In fine, this organ would possess no distinct and determinate action, although in such action its life consists (n. 310, 311).

449. *Meantime, whoever attentively examines and considers the origin, progression and outlets of these vessels, will see in them, and consequently in the heart, an image and representation of the state of the body and animal mind.* This follows as a consequence from articles n. 446, 447 of our induction, and from those relating to the foramen ovale (n. 355—358), between which and the vessels of the heart a comparison is instituted in n. 442, 443, 445. For if the general equilibrium of pressure pertaining to the arteries and veins depends upon internal causes, such as the affections of the mind, or upon external causes, such as the affections of the body, and if the abovementioned equilibrium be represented by the distinct determination of the coronary vessels, it follows, that there is thus a representation in the heart of the state both of the body and animal mind; and that according to this state, the general equilibrium, and conse-



quently the circulation of the blood, is regulated, and in conformity with the state of the circulation, the animal economy in general (n. 178—181).

450. We before observed (n. 294), that the slightest stimulus keeps the primitive corculum, with its early simplicity of structure, ambiguous with regard to the flux and reflux of the blood, or disposed to go off in whatever direction the force of the brain, as being the strongest, compels it, and that it thus commences and constitutes its own equilibrium, and that of its pulses and arteries. The equilibrium thus commenced in the primitive corculum, is retained in the adult state, but through the medium of the coronary vessels; for by these modes of transference of the blood proper to the heart, it is provided that the superfluous quantity of venous or arterial blood may not injure or destroy the natural state of the kingdom (n. 445—447). Thus it is that in the heart we find a representation of the body and animal mind.

451. If the field of least vessels be that where nature most especially plays, and celebrates all her animal sports, and those vessels depend on the governance of the brains more immediately than the larger; and if in the field of those vessels changes occur according to all the actions and affections of the brains, and which through the intermediate arteries affect the pulse of the heart; and if the least vessels be considered as placed in one extreme of the sanguineous system, and the heart as placed in the other, maintaining a mutual relation to each other through the medium of the larger arteries; and finally, if the heart itself be encompassed with a similar field of least vessels, according to our propositions (n. 234, I.—V.); it follows, that there is no change arising either from the brains or the body throughout the whole sanguineous system, which is not represented in the heart. When the *transferent* vessels (n. 437, 438) are multiplied beyond their due number, or open too widely, they represent a weak, timid, unsteady state of mind, and a corresponding state of body. With these transferent vessels the *retorquent* vessels of the left ventricle concur (n. 435), and the *anticipant* (n. 436); in fine, all those called arteries. On the other hand, the *retroferent* vessels (n. 439, 440) commonly called veins, if very numerous and open, indicate a firmness and

strength of the nervous, arterial and venous systems; and with these the *retorquent* vessels of the right ventricle concur. But the *refundent* vessels both of the right and left auricle, when they are present, and when multiplied and expanded beyond their just proportion, are significative of frequent changes of the body and animal mind; of irregular beats of the pulse, frequent inundations and palpitations. This is particularly the case whenever, instead of only a single large orifice of the right auricle, we find several in number, reciprocally communicating with each other by very conspicuous twigs (n. 428—430); to say nothing of other varieties which are as numerous as individuals themselves. The appearance of the heart depends principally upon these vessels; thus they always pursue in one heart a different course from what they do in another, and open with different orifices. Hence we may see how rude irregular motions and impulses occurring from day to day, deprive the machine of the heart, and the entire sanguineous system, of their integrity of state, forcing open passages which ought to be closed, constricting those which ought to be opened, and thus inverting the proper order: how by these means a nature is at length superinduced which rushes with blind instinct into the lusts that necessarily result from an altered fabric of the heart, in accordance with what we have observed on the subject of the heart of the turtle (n. 384).

452. *In which respect numerous affections may not improperly be attributed even to the heart, according to the usage of common discourse.* Thus we see a covenant of perpetual amity established between the brains and the rest of the body through the medium of the heart. For this reason an efficient cause existing in one, is in common language referred to the other, and more especially to the heart. Thus certain fluidists [*sanguinei*] persuade themselves that the soul has its residence in the heart, as though there were no more imperial organ for its abode, and no nearer seat from which its authority could be exercised. Hence the heart is designated as perfidious, sad, cowardly, envious, faithful, joyful, great, fearless, meek, mild; and what has its seat in the affections, is said to have its seat in the heart; and hence we have the terms heartless, disheartened, concordant, discordant; also in Latin, *excors*, *vecors*, *misericors*, &c.; be-



sides other terms which the mind, mistress of languages, has privileged as expressions. These expressions, we may observe, are by no means inapt, since the animal mind, as described, is represented in the heart (n. 451); to strive against which mind would often be to apply force to the heart, or were it unyielding, to do violence to it.

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453. By way of appendix we shall here subjoin a few remarks upon the composition of the blood in the heart. The right ventricle is as it were the great vat or cask of the system, in which all those fluids and essences are mixed together that form the ingredients of the red blood. In this receptacle one element is commingled with another, and in this state of commixtion, or rather convolution, they are all transmitted into the lungs, in order that the purely ærial elements, in the new chyle particularly, may be ejected through their secretory and excretory ducts into the now contiguous atmosphere, and that nothing but what is of a sanguineous nature, and kindly to the blood, may be transmitted through the veins to the left ventricle. But the heart is not only itself a general mixing vessel and vortex, but is also the first organ that operates to compound the blood. It is well known, that all the fresh chyle passes through the thoracic duct into the subclavian vein, and that when there is none for the mesentery to imbibe, the lacteal vessels convey lymph. It is likewise known that all the old, and also the recompounded blood in the veins, ascends from the entire system through the vena cava, and that the whole of the spirit which has once been excluded, gyrates through the medullary fibres of the brain, and all the new blood which is there eliminated by its chemical laboratory (n. 360), is carried downward into the jugular and subclavian veins. All these essences and menstrua, diversified as they are, are first conjoined with each other when collected in the right sinus of the heart; and in order to compose genuine blood, undergo continual changes, as explained in Chapter I. But before they experience their several vicissitudes, they undergo a state of preparation in the heart, which is not only a vortex for the reception of these elements, but *a vessel preparing and disposing liquids*

*for composition into blood.* This office the heart could not perform except by the translation and circulation of the blood through its proper arteries and veins ; for the heart is encompassed with a field of least vessels, in which field all natural chemistry is carried on, according to the structure there present (n. 234).

454. The new chyle flows, as I before said, through the thoracic duct, and the spirit, from the brains through the jugular veins, while all the fluids which are taken up by the first beginnings of the veins, are conveyed, together with the old blood, through the ascending cava. These liquids and fluids cannot at their first conflux in the heart, be so united with each other as to form red blood, in the red globules of which saline and subtle sulphurous elements of all kinds are most regularly associated and coördinated ; but suffer themselves only to be intermixed and rolled up without undergoing conjugal union. From the general action of the heart compared with the circulation of its proper blood through its arteries and veins, it is evident, that all the free spirituous fluid, together with the purer blood, is propelled into the abovementioned proper vessels of the heart, through which it performs its first circulation ; for we know from the physical sciences, that when corpuscles or globules of different kinds, and separate from each other, are impelled by one and the same force, each pursues its own course ; thus elastic corpuscles, which lose none of the impressed force, are put into a motion conformable to the nature of this force, and travel the fastest, while heavy and inert corpuscles, in which the force is absorbed and perishes as soon as impressed, travel only with a velocity equal to the difference between the force impressed, and the force lost by resistance ; or according to a rule of physics, in elastic bodies the force resulting from collision is equal to the antecedent collisive forces taken collectively, &c. (In non-elastic bodies the rule is different). The case is the same with respect to the liquids in the heart. Of all the animal fluids the spirit or spirituous fluid is the most volatile and highly elastic, next to which in volatility and elasticity is the purer blood, and next to this the red blood, (n. 100—102). If now there be any chyle, or any serum, which, from being associated with various kinds of essential salts,



possesses but a small degree of elasticity, it will follow, since these constituents have not yet undergone their conjugal union, that at the moment of systole, which is a strongly impulsive force, the most elastic among them, according to the laws we have cited, will move the first and foremost, and the rest in succession, according to their degree of elasticity and gravity. Hence that all the free spirit will travel first even through the minutest pores into the motive fibres, and animate its muscle. Now the heart is the first of the bodily organs to partake of the nectarean fluid conveyed from the brains, because the life of this organ is of the first importance, and therefore it should be the first to taste of the cup, before passing it to the others. The fibres of the heart are therefore provided with the first and purest essence of all. The other parts of the blood, which are inert, and are nevertheless enclosed in the ventricles or lacunæ proper to the heart, either enter no farther [*excubant*], or if urged into the fleshy ducts, are at the moment of diastole sent into the coronary veins, or back again into the lacunæ; for during diastole, the commissaries of the heart lie open, as before observed.

455. But let us pursue still further the subject of this spirituous blood, and see how it circulates through these vessels, as so many serpentine channels, in order to intermix again with the blood. The blood that passes through the refundent vessels, and that which passes through the retorquents of the right auricle and ventricle (n. 433, 434), immediately returns into the general sanguineous stream, with which it associates after having completed its circuit. It does not join the former sanguineous current, which is already expelled into the lungs, but it joins the new current as it flows in from each cava, and in which it is better prepared to take its place. If, however, it does, not yet combine with this stream, but flows free, it is again propelled, as before, by the force of the heart into its motive fibres and filaments, and returns into another sanguineous current. This it can do two, three, or four times over, before it allows itself to be conveyed into the lungs, in consociation with the other currents. The most purified blood moreover comes from the left ventricle, through the retroferent vessels (n. 439), that is to say, the blood that has been once carried through the

lungs, and then returns into the right auricle. The purest blood is thus transmitted through the retorquent vessels; that is to say, the blood that has not yet reached the lungs, is mingled, in the proper vessels of the heart, with the blood that has once, or perhaps twice, passed through the lungs, and come in contact with the atmosphere. It is in the performance of these operations that the chemistry of the heart, or its preparation of the blood, appears to consist,—operations which take place in order that the blood may be duly constructed, by acts of discrimination, sequestration, division, and reabsorption (n. 199).

457.\* The other substances, as the free urinous salts, are expelled through the muscular layers principally toward the base of the heart, and it is for this reason that there is here such a collection of fat; they are also expelled toward the division of the ventricles, from which the foregoing muscular layers begin, which is also the most tranquil region of the heart, where the muscular planes are more relaxed, and the coronary vessels are largest. It is only in this direction that the common action of the heart can send those particles that, after the division of the globules, flow in a free state, and become as it were the elements of an extremely fine fat. But the lymph that is separated, is sent by the proper vessels of the heart to its surface, which for this reason is seen to be irrigated with so great a number of lymphatics.

458. There is a great similitude between the vessels of the heart and those of the brain, so great indeed, that with no others can the latter be compared better than with the former. For, 1. The vessels of the brain depend on its general action, and commence and complete their systole and diastole, as the brain does its animation. So the vessels of the heart are actuated solely by its general motion (n. 420). 2. All the large and small cavities of the brain, lie in the stream of its motion, as those of the heart lie in the stream of the heart's motion, namely, not only the coronary vessels, but also the fibres, fleshy ducts, lacunæ, and ventricles (n. 420), as well as the lymphatics (n. 457). 3. When the vessels of the brain are opened, they are drawn apart laterally, and at the same time shortened. So also

\* An error occurs here in the numbering of the paragraphs in the original.—(Tr.)



are the vessels of the heart (n. 349). 4. The vessels of the brain perform their diastole when the brain compresses itself, and *vice versâ*; the same is the case with the vessels of the heart (n. 423—427). 5. In the vessels of the brain there is a species of physical attraction, or of pumping, as in syringes (n. 349); the same thing is found in the vessels of the heart; for when they are stretched laterally, and at the same time shortened, the blood necessarily flows into the space thus created. 6. During the constriction and extension of the vessels and sinuses, there is no passage from the arteries of the brain into the veins, or from the veins into the sinuses; but only during the period of the dilatation or impletion (n. 349). The inverse of this is the case with the vessels of the heart. During constriction, their communication is open by means of the commissaries between the arteries and veins of the heart, or between the lacunæ and superficial vessels (n. 409, 410, 417). At the time of their expansion, all communication between the arteries and veins is taken away, nor is there any passage from the arteries except into the motive fibres (n. 414). The reason of their differing from each other in this respect, is, that nearly all the superficial vessels of the brain are arteries, (the veins being rejected to the extremities of the hemispheres, or to the large sinuses,) while all the superficial vessels of the heart are veins (n. 421, 422).

459. We have said that nearly all the superficial vessels of the brain are arteries, the object of which is, that the brain may be always in possession of strength and life; for the strength and life of the body lie in the arteries (n. 231); and internally in the brains there is scarcely anything beside the cortical and medullary substance which forms itself into the nervous substance of the body. But the strength of the heart arises from the state of the blood in general that flows into its ventricles, hence towards its interiors; which become immediately filled. Hence the arteries of the heart lead from its interior sinus into its muscular substance, while the veins are rejected to the surface. This is a sign, that the action of the heart is from within to without, and the action of the brain from without to within, or that the brain concentrates all the forces of its body upon itself; while the heart, on the contrary, effuses all the forces of its body from itself. Thus every cause proceeding

from the brains is internal, and every cause proceeding from the heart or blood is comparatively external. Hence it is manifest, that each particular viscus of the animal body has its own science of angiology, or its own particular doctrine of arteries and veins. It is evident also that this doctrine, although the first that is propounded, must nevertheless be the last that can be brought to perfection (n. 1).



## CHAPTER VII.

### THE MOTION OF THE ADULT HEART.

460. BOERHAAVE. "The heart and its auricles are real muscles, and act with a muscular force; they act, that is to say, when all its fibres, simultaneously shortened, diminish the length of the heart, increase its breadth, accurately contract the cavities of both ventricles, dilate the tendinous lips at the mouths of the arteries, shut down the lid-like valves of the venous orifices, and express the contained liquids with great force, through the dilated mouths, into the arteries. This is the systole, or violent contraction of the heart, in whose structure there seems to be a wonderful and occult propensity to perform reciprocal acts of systole and diastole, and this, not only during life, but even after death; nay, after the heart has been separated from the body, and even when it is cut in pieces. And that the blood is then forced out, and propelled by this muscular contraction, is proved by its jetting forth when the pulmonary artery, or the aorta, is opened near the heart in a living animal; by its expulsion from the heart, when the cone of the latter is raised upwards, and a slice or section taken from its apex; by the pressure upon the finger when inserted into the wound thus made; by the swelling, tension, hardness, and paleness of the fibres; by their contraction succeeding and not preceding the act of impletion; and by the depletion being concomitant upon the shortening of the heart. If the eighth pair of nerves be tied, or divided, in the neck, the motion of the heart languishes, palpitation ensues, with great distress to the animal, and in a short time the motion wholly ceases; which shews that the origin and continuation of the systole of the heart is attributable to these nerves. . . ." (Observe, this is according to Lower; but as to whether it be true or not, see Morgagni, *Advers. Anat.* v., Anim. 18.) "When the blood is thus almost wholly expelled from the cavities and vessels of the heart by its systole, its [muscular] fibres grow flaccid,

from the compression of their nerves by the dilatation of the large arteries; and the coronary arteries being empty, the fibres are narrowed and elongated, and the distance between the base and the apex of the heart is increased; the pressure of the walls on the cavities is taken off; the valves of the venous inlets [from the auricles to the ventricles] are drawn toward the apex of the heart by the fleshy columns to which they are attached; the auricles and venous sinuses contract, and fill the cavities of the ventricles. This is the diastole, or the natural state of the heart. For that at the time of diastole the ventricles of the heart are filled with blood, may be demonstrated by opening one of the large arteries near the heart; by turning the heart of a living animal upward, and cutting it transversely, when it will be seen to receive the blood during diastole, and not to discharge it; by the inspection of animals opened a little before death; by the absence in diastole of pressure upon the finger when inserted into the ventricles through an incision. It is evident therefore that the blood does not pass out of the heart from any rarefaction, but from the muscular force of the organ. (*Inst. Med.*, n. 187—191.)

“The blood conveyed to the venous sinus, may be driven by its hollow muscle into the right auricle, when relaxed, for there is then nothing to oppose it, but its progress is assisted by the motion of the subsequent venous blood pressed in the same direction. But since the right auricle, like the left, is a large, hollow muscle, furnished with innumerable arteries and veins, and composed of two rows of strong fibres, running in contrary directions to opposite tendons, and leaning by one tendon on the venous mouth of the right ventricle, while it is attached by the other and harder tendon, which is nearly circular, to the vena cava; it is evident, that by the contractile force of this last, the blood may be expelled with a powerful impetus into the right ventricle, when relaxed. For the heart being then empty and elongated, and the three tricuspid valves drawn back towards its sides and apex, by the tapering and oblong fleshy papillæ arising from the sides of the right ventricle, and which are themselves also drawn back; and hence the passage being sufficiently open, there is nothing at all to obstruct the entrance of the blood. The structure of the part, the phenomena presented by vivisection, inflation and injection, all prove the same thing. (*Ibid.*, n. 147—150.)

“The venous blood, therefore, (that is, of the whole body,) is carried with a perpetual, swift, and violent motion, from the venous sinus, through the right auricle, and through the right ventricle, into the pulmonary artery alone. The left venous sinus receives all the pulmonary blood from the four great concurrent pulmonary veins, and by its



muscular action is enabled to propel it into the left auricle, when relaxed, (which auricle is much smaller than the right, although similarly constructed and situated,) for there is nothing to prevent the blood from entering. So for a like reason, the blood can be easily propelled into the left ventricle when relaxed, through the two mitral valves, which have a similar mechanism to the tricuspid mentioned before ; but it cannot return the same way. Moreover, by the action of the three semilunar valves placed at the beginning of the aorta, the blood is again determined straight into the aorta, for the same reasons as alleged above, and this, especially if the aorta be quiescent ; and the passage is accurately closed against the return of the blood. We are here speaking of the adult subject, and of those of our species who live in the usual manner. All the pulmonary blood, then, is conveyed with a continual, rapid, and violent motion, from the lungs into the left venous sinus, the left auricle, and the left ventricle, and so into the aorta. This motion is clearly accompanied with the following circumstances in the living subject. 1. Both the venous sinuses are filled, turgid, and red, at one and the same time ; and so are both the auricles. 2. Both the auricles become flaccid at the same instant, and so also do both the venous sinuses. 3. At the very moment that the auricles become flaccid, they are filled with blood, by the impulse of that in the veins, and by the contractile action of the adjoining muscular venous sinus. 4. At the same instant, both ventricles contract, are emptied of blood, become pale, and the two great arteries are filled and dilated. 5. At the moment after this constriction, each empty ventricle is flaccid, elongated, and reddened, and its cavity enlarged. 6. Scarcely has this happened, when both auricles, and both muscular venous sinuses, contract with a muscular motion, express the blood they contain, and propel it into the ventricles ; and now the auricles become pale. 7. In the meantime the venous sinuses and auricles are again filled, as before ; in fine, the same series of acts occurs again, and so continues till the fainting animal is just dead. 8. When death approaches, the auricles and venous sinuses palpitate several times to one contraction of the ventricles. At length the left ventricle first ceases to move, and then its auricle ; afterwards the right ventricle is still, and last of all the right auricle. The animal is now dead, after which we find the left ventricle empty, but the right ventricle always full of blood. Thus it appears that all the blood brought back from every point of the body, internal and external, and from every point of the heart, and from the auricles, is driven collectively into the right ventricle, thence is transmitted through the lungs into the left ventricle, and thence is sent all over the

body, from whence it returns again to the heart. And this is the continual circulation of the blood, the glory of which discovery, with the proofs and explanation of it at large, will confer immortality on the name of Harvey, whose doctrine has been confirmed by injection and transfusion, and has received ocular demonstration from the microscope. (*Ibid.*, n. 155—160.)

461. "The heart is also composed of muscular fibres, which arise from four circular tendons, encompassing the four apertures of the ventricles, into which tendons most of the fibres are also again inserted. From these tendons arise, 1. A small number of slender fibres, which run in almost a straight line from the base to the apex on the outside of the right ventricle only, serving to strengthen the muscular substance of that ventricle during its systole, and to assist it in expelling the blood. 2. Underneath these, in the same ventricle, arise other fibres, from the left side of the heart, which ascend obliquely towards the right side, take a spiral course, and terminate in the base. 3. Under the last fibres again, there are others which run from the right side of the heart to the left, encompass and embrace both ventricles, and rising to the base of the left ventricle, form a contrary spiral to the series mentioned before. These two last classes of fibres are common to both ventricles, and equally invest both. On all sides equally they constrict the entire heart, with opposite, synchronous, strong contractions, constringing both ventricles at once by pressing them against the middle septum, and drawing up the apex towards the base of the heart. In this operation they are assisted by another series of fibres, which, 4, pass in a varied curve round the former, and are implicated with them, serving to bind them together, and retain them in their places. But the left ventricle has in addition two other thick series of fibres peculiar to itself, the outer of which, lying under the former (2, 3, and 4), ascend spirally all round the left ventricle towards the right, and forming part of the septum, terminate in the base of the left ventricle, the cavity of which they entirely surround, and are also confined or secured by other fibres of their own like those mentioned in class 4. Finally, 5, under the preceding series there is another and a last, which descending in an oblique spiral from the base of the left ventricle, toward the right side of the heart, compose the internal substance of the left ventricle, and after completing the middle septum, are spent in curves of different lengths, variously contorted. Add to these, that the fleshy columns, and the excavations in the parietes of the left ventricle, give it the power of exercising a very strong and close contraction, both general and particular : while the other fibres, and the little columns that



grow in the cavities of both ventricles, serve to shut the valves when the heart is in systole, and to open them again when it is in diastole.” (*Ibid.*, n. 184).

462. HARVEY. “In the motion of the heart, and during the time thereof, three principal things are to be noticed. I. The heart is erected, and rises up in a point, striking against the breast, and causing a pulsation that may be felt externally. II. It contracts all round, but more especially toward the sides, making it appear of smaller dimensions, and elongated and drawn together. If we take out the heart of an eel, and place it on a table, or on the hand, this will be manifest. It is also well seen in small fish and cold-blooded animals, that have conoid or elongated hearts. III. If a heart be grasped in one’s hand, it will become sensibly indurated at the time of its motion. . . . IV. It may further be observed that in fish, and cold-blooded animals, as serpents, frogs, &c., the heart is of a whitish color during its motion, but when it is at rest, it is of a deep blood-red. (*Exercitatio Anatomica de Motu Cordis*, cap. ii.) Further, in the motion of the heart the following circumstances are to be observed, which also belong to the motions and pulsations of the arteries. I. The time when the tension and contraction of the heart, and the percussion of the breast, take place, is the time of the systole of the heart. At this time the arteries are dilated, produce the pulse, and are in the state of diastole. So at the same time the ventricles are contracted, and force out the blood they contain, the arterial vein pulsates, and is dilated together with the aorta and the other arteries of the body. II. When the left ventricle ceases to move, pulsate and contract, the pulse of the arteries ceases; and when its action becomes languid, the pulse in the arteries is scarcely perceptible; and in like manner when the motion of the right ventricle ceases, the pulse stops in the arterial vein. III. So when any artery is divided or perforated, the blood is thrown out with force from the wound during the contraction of the left ventricle. And when the arterial vein is divided, we see the blood jet out with force at the time of the tension and contraction of the right ventricle. (*Ibid.*, cap. iii.) When the animal\* is nearly dead, the heart ceases to respond with its motion [to the motion of the auricles],† and only slightly nods its head, moving so faintly that it seems to offer but a sign of motion to the beating auricle. Thus the heart ceases to beat before the auricles, which therefore may be said to survive the ventricles. First of all the left ventricle

\* Harvey is here speaking of fish and cold-blooded animals.—(*Tr.*)

† It is to be observed that by the heart the old anatomists frequently mean the ventricles only, and not the auricles.—(*Tr.*)

ceases to beat ; then the left auricle ; then the right ventricle ; and at last, (as Galen also observed,) when all the others have given up their motion, and are dead, the right auricle still beats, so that the life appears to remain in it the latest. While the heart is gradually dying, one may see it, after two or three pulsations of the auricles, sometimes in a manner wakening up and responding, and slowly and with difficulty performing or essaying a single beat. But we must particularly remark, that after the heart has ceased to beat, although the auricle still beats, if we place a finger upon one ventricle, each particular pulsation will be felt in the ventricles ; just in the same manner, as we before said, that the pulsations of the ventricles are felt in the arteries ; that is to say, on account of the distention occasioned by the impulse of the blood. And at this time, when the auricle alone is beating, if we snip off the apex of the heart with a pair of scissors, we shall see the blood flow out at every beat. . . . It is to be observed, that when I speak of pulsations in the auricles and heart, I always mean contractions. . . . In fishes, frogs, and similar creatures, which have one ventricle, and instead of an auricle have a certain bladder or vesicle placed in the base of the heart, and gorged with blood, you will see this vesicle contract first, and the contraction of the heart most evidently come afterwards. . . . The heart of the eel, and the hearts of some other fish and animals, even when removed from the body, beat without auricles ; and in fact, if you cut them in pieces, you will see these pieces contract and relax by themselves ; so that in these cases the body of the heart beats and palpitates after the auricles have ceased to do so. . . . On making the experiment in a pigeon, after its heart had quite ceased to move, and even the auricles were still, we found that by wetting the finger with saliva, and placing it warm upon the heart, the latter recovered its force and life, and it and the auricles again moved, contracted and relaxed, and were in a manner recalled from the shades of Orcus. . . . I observed on several occasions, that after the heart itself, and even the right auricle, had left off beating, and were as it were *in articulo mortis*, there manifestly remained an obscure motion, and a kind of inundation and palpitation, in the blood itself that was contained in the right auricle," &c. &c. (*Ibid.*, cap. iv.)

463. LANCISI. "In order to find the hitherto vainly-sought mechanical reasons for the alternate motion of the heart, we shall treat . . . of the coronary arteries and veins, and of the nerves that creep through the heart's substance. . . . For when these are in a normal state, the motions of the præcordia are just and natural ; but when they are depraved, or any irregularity occurs in their situation, number, figure, and size, or in any the least conditions of fullness, or empti-



ness, the motions then very soon become preternatural. (*De Motu Cordis*, &c., lib i. sec. iii. *De Vasis particularibus Cordis*.) Not to mention that several eminent anatomists have thought that the heart has naturally no nerves, we may observe that Thomas Willis, Pierre Dionis, and Laurence Bellini, have not feared to assert, that its nerves are exceedingly small, and scarcely deserving of notice. And although we are not ignorant that the accomplished Fallopius was among the first who furnished a guiding light to such of his successors as were about to travel in this dark and pathless way, and that Vieussens, and especially Lower, as well as Munnicks, and other more recent authors, have followed in his footsteps, yet perhaps it may not be thought altogether useless, if to their discoveries I add the results of my own observations. (*Ibid.*, cap. iii. *De Nervis Præcordiorum*.) [In horses and oxen] as soon as the larger arteries are drawn apart, a multitude of nerves comes in view, and wherever the external coats of the vessels are removed, but particularly on the posterior surface, a beautiful nervous network is discernible. (*Ibid.* prop. 47.) There are five pairs of nerves on each side that supply considerable branches to the heart; of which five pairs three arise from the root of the spinal marrow inside the cranium, while the other two arise also from the spinal marrow, but outside the cranium. I. The first is the par vagum. . . . II. The second is the pair . . . called by Willis and others, the internal intercostal, but which we . . . shall name the superior and tendinous intercostal. III. Among those that arise within the cranium we reckon the vertebral, which forms the second ganglion beside the last cervical vertebra. The first of the pairs that arise from the spinal marrow outside the cranium, and that give off the fourth class of cardiac nerves, is the inferior intercostal, which forms the third ganglion. The last pair is the phrenic, without any visible ganglion, which arises from the spinal marrow, sometimes opposite to the last cervical vertebræ, sometimes together with the axillary nerves opposite to the first dorsal vertebræ. . . . Beginning first on the right side, we see the par vagum running down in company with the jugular vein into the thorax, and there giving off a branch that embraces the axillary artery on the same side, and then becomes recurrent. After this it sends out various twigs on all sides, and penetrating the pericardium in company with the vena cava, puts forth a branch that goes to the right auricle, and afterwards another that runs back under the pulmonary artery, but sends its larger offsets to a large plexus, that lies posteriorly in the base of the heart, between the pulmonary artery and the aorta, just in fact where the ductus arteriosus passes between those two great vessels. This plexus merits the most particular attention. For a multitude of nerves from each of the five

pairs concurs to produce it, and it again gives off innumerable nervous filaments to the inner substance of the heart. . . . From the ganglion of the superior intercostal nerve, (which ganglion is situated between the first and second cervical vetebræ, near the internal carotid artery, and under the jugular vein and the par vagum) in addition to many as it were tendinous branches that are supplied to different parts of the neck and tongue, and to the upper parts of the thorax, three very conspicuous branches proceed under the carotid artery, and afterwards within the thorax, mount up over the aorta; and then penetrating the pericardium, one of them runs over the pulmonary artery, and is distributed directly to the anterior substance of the heart, and accompanies a branch of the coronary artery, and plunges with it into the muscular lacerti of the heart. The two others (just as we observed of the par vagum,) reach the plexus abovementioned, from which they are distributed largely and abundantly to the muscular substance of the heart. The third or vertebral nerve, . . . after coming from the second ganglion, divides into several branches, the chief of which proceed through the right side of the thorax, along the descending cava, to the pericardium, and go by the same course as the superior nerves to form the plexus; from which afterwards, as from a larger fountain, rivulets of nerves penetrate and irrigate the heart itself. The fourth, or inferior intercostal nerve, . . . is furnished with the third ganglion, from which branches not a few, passing through the pericardium, creep over the superior cava and right auricle, and are distributed to the heart, to assist in forming the abovementioned plexus. Finally, the fifth nerve is the phrenic, . . . which after penetrating the thorax, closely embraces part of the superior vena cava, and externally the pericardium itself, the membrane of which it supplies with certain nervous fibres, and from this membrane creeps through the annexed trunk of the superior cava, not only to the right auricle and ventricle, but also to the plexus above alluded to. The nerves that proceed from the five foregoing pairs, direct their course on the left side in a similar manner, and terminate in the heart. . . . From the left trunk of the par vagum, a little below the recurrent branch, another offset proceeds, which is reflected, and dips both into the left auricle and into the plexus we have so often mentioned; from which afterwards nervous fibres are diffused into the substance of the ventricles. And it is worthy of particular remark, that on the left side, from the second pair of nerves, that reach [*pertingunt*] to the heart, a large branch issues from the superior ganglion, and descending along the carotid artery, as soon as it reaches the aorta, enters its external coat, and penetrating the pericardium (besides the offset that it sends over the external surface of the heart, to accompany the coronary



artery on the back part of the same) is immediately inflected when it comes in contact with the pulmonary artery, and like a new stay binds down the trunk of the aorta, where it is attached internally to the pericardium; and then becomes recurrent to the trachea and œsophagus; a circumstance which I am not aware that any anatomist has hitherto described. (*Ibid.*, prop. 48.) From what we have said of the wonderful communication between the nerves of these five branches on both sides . . . the reason may be given why when the par vagum, for instance, or any other of the nerves on one side, is tied, the motion of the heart, although disturbed, does not cease entirely; for we should have to tie the nerves of all the pairs at once, which nerves, as we have shewn, are ten in number, in order to produce this effect; an operation which is scarcely possible, at any rate without the animal be dead previously. (*Ibid.*, prop. 49.) From each of the five pairs of nerves, . . . offsets are sent below the heart, and again ascend through the vena cava inferior all the way to the right auricle. Certain it is . . . that the nerves of the par vagum, the intercostal nerves, both superior and inferior, and the vertebral nerves also, after passing out of the thorax, below the diaphragm form the renal plexus, or as others call it, the stomachic plexus, although it is found between the renal capsules. From this plexus we see a number of twigs inserted into the inferior vena cava, and wonderfully ascending along its membranes, with an ivied twine, all the way to the right auricle. . . . But the nerves recurrent from the phrenic pair along the cava, proceed as follows: large branches are distributed to the nervous centre of the diaphragm, and send evident twigs to the vena cava, at the place where it perforates that septum, which twigs ascend, together with the other nerves above described as recurrent from the lower belly, to the right auricle and ventricle. [That these twigs ascend] is evident, because their branches below the diaphragm are of comparatively large size, and gradually diminish as they ascend, till at length they are obliterated and disappear in the right auricle, and at the mouth of the right ventricle. (*Ibid.*, prop. 50). The nerves that are sent over the external and anterior surface of the heart, descend along the outside of the pulmonary artery; but those that are distributed over the posterior surface, run at the side of the aorta. But in both cases, (with the exception of the fine threads that are lost on the outer membrane of this viscus,) they entwine the trunks and branches of the coronary arteries, as ivy wreathes its clasps around the trunks of trees: and indeed they strengthen and invest the arteries as it were with little nervous sheaths. And here it is worthy of remark, that a far larger quantity of nerves is supplied to the coronary arteries, than to the accompanying veins, the membranes of which

latter have indeed some minute nervous twigs, but neither so many in number as those of the arteries, nor adherent from the base to the apex, with the wonderful and winding intertwinement which the membranes of the arteries present: for in the veins they appear to creep along, and to become as it were reflected from the apex to the base. . . . And here we have observed, not without admiration, that the little nerves that accompany and invest the small arteries, are inserted and penetrate chiefly at the parts where the latter are strengthened with delicate sphincters, as we said above. (*Ibid.*, prop. 51.) We once macerated a human heart in water (often changed) for 40 days. This heart, after having all the blood squeezed out of it, weighed 8 ounces. . . . We observed more particularly, I. That when weighed again after 20 days, its weight was only 5 ounces. . . . II. On examining its then flaccid substance, we found it consisting entirely of three different kinds of components; namely, first of blood-vessels; secondly, of nervous branches and villi; and lastly, of a confused medley of fibres, formed of a vascular and nervous network. With respect to the nerves, we could clearly see that they everywhere accompanied the blood-vessels, and always became greater, and were augmented, within the heart, leading to the inference that the heart itself is a peculiar origin of nervous structure. For the tendons of the valves and columns of the heart are all interwoven with nerves, so that it is surprizing to see a twine and mesh of them in every part, and particularly in the internal parts, and in the vicinity of the mouths of the large vessels." (*Ibid.*, prop. 52.) See also *Ibid.*, tab. vii.

464. "That the heart is a muscle suspended in the thorax has been admitted by all. . . . For if the breast be ever so little opened, and the pericardium be cut, the heart immediately presents itself, appended to its vessels, which are loosely connected both with the lungs, and with the throat, head and axillæ. (*Ibid.*, prop. 27.) As soon as we touch the heart, we discover four lacertous and fleshy bellies, and in these bellies separate and distinct sinuses, whereof two, which are comparatively flaccid, are called auricles, and the rest ventricles: the right soonest yields to pressure, the left is rather hard and resisting. When the entire heart is stripped of its external membrane and adipose follicles, we immediately see, even from the outside, four tendons, called the circular tendons, which are variously and separately located with regard to each other. In the base of this viscus there are at least two; by one of which, placed anteriorly, the right ventricle is firmly bound, and continued to the pulmonary artery; by the other, which is for the most part placed posteriorly, the left sinus is similarly connected to the aorta. We then see two other tendons, although much looser, at the sides of



the base of the ventricles; one, which occupying the place on the right, connects and unites the right ventricle with its sister auricle, and with the stem of the vena cava; the other, which occupying the left but slightly posterior situation, connects and unites the left ventricle with the left auricle, and with the stem of the pulmonary vein. But the fleshy fibres that constitute the four walls of the sinuses, terminate for the most part in these tendons. . . . It is plain, therefore, that both the fleshy and tendinous fibres, are so disposed (*advolvi*) on the auricles and ventricles, and so decussate with other fibres, as to form the tissue of but one organ,—the four-chambered muscle of the heart. Yet I think it should here be observed, that these four tendons, disposed in the form of sphincters, and applied to the mouths of the heart, become converted into four other tubular and very long tendons, which are distributed throughout the body, and denominated arteries and veins. . . . To the tendons abovementioned, we do not add the long but not hollow tendon described by some writers, and which running externally from the base to the apex, takes up and collects only the external fibres of the heart; for this long whitish fillet is not a legitimate tendon, and in fact is no more than the strong external membrane of the coronary artery, which descends from the base to the apex, and has been an occasion of mistake to several anatomists. But the heart is seen to be a quadricave or four-chambered muscle still more clearly, when we open its sinuses, for we then find within the ventricles eleven other tendons constructed with amazing ingenuity; some of them common to the ventricles and their arteries; while they all tend principally to connect together the four internal vaults of the heart, and to make them stronger. (*Ibid.*, prop. 28.) The hollow muscles in the body are produced by a varied twisting of villi and fibres round determinate cavities, and more or less by the application of the spiral form especially.\* . . . That nature has applied this wonderful law of formation to the heart particularly, no one will deny, who observes that this four-chambered muscle is made and constituted of many rolls of fibres, some almost straight (as seen chiefly in brutes that hang down the head) and transverse, and others, and these the greater number, spiral, and for the most part decussating with, and intersecting each other. (*Ibid.*, prop. 29.) We shall begin from the trunk of the vena cava, where it is . . . joined with the pericardium and the diaphragm. In the first place, then, extremely minute, and intorted and agglomerated fibres, form in this situation a circular muscle, not unlike a sphincter. . . . From this the fibres are

\* Lancisi here adds, that “Galileo was the first to teach the important properties and powers of the spiral, in his *Mech.*, p. 10, where he speaks of the art of rope-making.”—(*Tr.*)

continued spirally (yet with some tendency to a circular course) toward the heart, decussating with each other, and become more fleshy as they proceed, until they are so mingled with other fibres, that are applied to the superior cava, as to constitute and comprehend within them that uppermost vault of the vena cava called by us the vestibule, and which is the commencement of the right auricle; which auricle these lacerti beautifully form by processes of divarication, multiplication, collection into unequal fascicles, and intermixture with each other. In like manner the vestibule of the pulmonary vein, and the vault of the left auricle, is produced by the varied application and intertexture of fibres; although in this place the fibres . . . do not constitute so evident a sphincter, and are not so numerous or strong, as in the vena cava and right auricle, through which the blood is sent with less velocity, and therefore needs a greater circumpulsion from the fibres. And as on the anterior surface of the heart, which is the nearest, bundles of fibres are sent from the vena cava and right auricle, so on the posterior surface, bundles of the same are sent from the pulmonary vein and left auricle, both outwardly, and within the cavities; and it is of these fibres that the compact substance of the ventricles, and particularly of the left ventricle, is made up. Thus a multitude of lacerti, partly divided into fascicles, arise externally from the auricles and heads of the veins; and after forming, by their greater mutual adhesion and contorsion, the loose round tendons of the heart, communicate and are continuous with the series of fibres that make up the external surface of the heart. In like manner more tendinous bundles are continued from the internal surfaces of the heads of the veins, and of the auricles, and compose the internal structure both of the tricuspid valves, and of the surfaces of the ventricles; following a similar mode of propagation to that observed in the formation of the semilunar valves and larger arteries. But all these things are so done, that the fibres inosculate by diversified and innumerable advolutions, the external fibres with the internal, and the internal with the external, seeming to constitute a Gordian knot, and suggesting to the mind what Hippocrates says, ‘that when a circle is once described, its beginning can no longer be found.’ (*Ibid.*, prop. 30.) There are three principal arrangements, and modes thereof, whereby a strong contexture of fibres, and one which powerfully resists disruption, is produced around the ventricles of the heart. The first lies in the contrivance of drawing the fibres from the external surface of the auricles, and of the heads of the veins obliquely, and as it were spirally, through the external part of the ventricles, all the way to the apex: which fibres, consequently, always enlarged in bulk, make up the thick cortex of the ventricles; excepting only a few that penetrate as it were directly in-



wards in the middle of their course, and bind the spiral fibres here and there. . . . But when the spiral fibres reach the apex, they make a single and loose turn upon themselves, and are carried inwards, and beautifully constitute the inmost surface of the ventricles, and especially of the left ventricle, together with their tricuspid valves, so that it is doubtful whether this order of fibres is spent on the internal substance of the auricles, veins and arteries, or whether it arises from that substance. . . . For it is evident enough, that the internal parts of the ventricles, and the tendinous cords of the above valve, arise from the same fibres of which the external surface of the ventricles is constituted. The second and much more wonderful mode of weaving the fibres for the production of the ventricles, is that which we observe is covered and concealed as a treasure by nature, between the beforementioned bands of spiral fibres, which we have described as making up first the external, and then, by a further production, the internal surface of the heart. For other layers of many kinds of fibres, which occupy the centre of the thickness of the walls, particularly of the left ventricle, are held closely within the doubled bag of these fasciæ. These layers of fibres take a direction more or less inclined to the longitudinal diameter of the heart; so that some of them form [with it] an acute angle, some almost a right angle. But these as it were bound fibres, do not run so as to pass through the apex into the cavities, but they run back for the most part inwardly, but a little inferiorly, to the circular tendons placed at the base of the heart, from which they arose exteriorly, but a little superiorly. . . . The last and most beautiful contrivance by which the fleshy substance of the ventricles resists the distraction and dissolution threatened by its own motions, is that rare wicker-work by which both the ventricles, tied together as they are by the middle septum, are cunningly supported at the same time that they are distinguished. . . . These cysts, which have a double cavity separated by a partition, are so framed, that the osier twigs, [to pursue the comparison,] which have begun to constitute the right sinus, for instance, when they have reached the septum, are there twisted, implicated and decussated, not in order to remain there, but to be prolonged onwards to the opposite side, and to weave and environ the left cavity. . . . That nature has adopted the same kind of wicker-work in compacting the fibrous structure of the ventricles, is attested also by the columnar muscle (like the chain we use in supporting houses) that is found within the right ventricle of the heart in certain quadrupeds, and especially in the ox. This muscle runs transversely from the septum to the external and thinnest wall of the right ventricle, where the pulmonary artery opens, and is attached at both ends by a wonderful piece of stitching and

weaving. . . . But in human hearts, in place of this muscle we generally find one or two little fleshy lacerti, running the same transverse course. (*Ibid.*, prop. 31.) We said above, that the heart has four principal tendons, and these of a circular form ; although the two that join the auricles with the ventricles, do not appear to enclose an exact circle. For as those segments of them that are connected with the arches of the auricles are truly tendinous in structure, so the inferior segments, which are joined with portions of the heads of the veins, externally appear a little more fleshy, although interiorly they are supported by the loose tendinous substance of the tricuspid valves. We have labored assiduously to unweave by art, the structure of the circular tendons, so closely woven as it is by nature. . . . It occurred to us to macerate the heart in vinegar, which succeeds well, provided it be the heart of a robust youth, . . . but not so in the hearts of old men, where the tendons particularly that stand at the heads of the great arteries, are extremely dry, and almost cartilaginous, (in old stags indeed they become ossified,) and are with the greatest difficulty unravelled. . . . By the term tendon we are not to understand a something that is not muscular. For a tendon is a very compact adhesion and intertexture of attenuated fleshy fibres, more or less strengthened by the addition of transverse villi ; which fleshy fibres do not admit the red part of the blood into the narrow channels of their vessels and pores, and are therefore in general rather white than otherwise. . . . To return then to the subject ; the circular tendons we have spoken of, are formed by the prolongation, attenuation, and greater condensation of the fibres, of which the whole mass both of the heart and great vessels is made up. Thus if the fibres disposed upon the ventricles be regarded before they are produced to the auricles and heads of the veins, or contrariwise, . . . we shall clearly see that they form by a most beautiful interweaving circular tendons, but which more closely approximate to the muscular texture. Likewise that fibres are sent from the ventricles to the large arteries, after forming the very firm and strong texture of the other two tendons. And although the structure of the four circular tendons consists of various fleshy fibres, both mutually superimposed, and interwoven more or less tightly and crosswise ;—of the fleshy fibres of the heads of the veins, and of the auricles, which pass into the ventricles, and so into the great arteries ; yet we ought to mention that the weaving of the circular tendons in the confine between the auricles and ventricles, is somewhat different from that of the two other tendons conjoining the ventricles with the great arteries ; for the first is more simple, redder, and less strong, and hence but little different in texture from a muscle ; but the other is more compound, compact, white and robust, and in a word, is



truly tendinous. If (after having stripped off the external, as also the internal, strongest, and manifestly tendinous membrane) the tendons that are continuous with the auricles and ventricles, be held up to the light, their structure appears like a web, composed of various planes of filaments going off in different directions. Thus on one surface the fibres run from the right of the auricles to the left of the ventricles ; but on the other from the left of the auricles to the right of the ventricles ;\* while many again pass semicircularly, or are otherwise dispersed in various ways, without observing any ascertained law, and support and strengthen the proximate planes. Wherefore these tendons do not appear to differ in texture from the ventricles or auricles, except in the comparative fineness of the fibrils, and their mutual interlacement and adhesion. But the case is otherwise with the texture of the round tendons, which are between the heart and the large arteries, and which as it is stronger, so is it more indistinct than the texture of the tendons beforementioned. I will, however, candidly state the result of my observations after repeated experiments. The fibres, then, of which the different planes multifariously applied to the ventricles are composed, are collected into small and numerous bundles of an evidently tendinous character, and proceed to form these tendons ; and these bundles, or rather little cords, ever becoming smaller, are wonderfully implicated with each other by various decussations, and so closely adhere together, and are so twisted or contorted, that they have the appearance of tow, forming an inextricable farrago of fibres, which is very strong at the orifice of the aorta, but less robust at that of the pulmonary artery ; till the same cords, emerging from the tendons, are in looser contact with each other, and become more distinct in the texture of the arteries. . . . Nor must we omit to mention, that certain very strong fascicles of fibres from the ventricles, climb over the tendons in decussating rows, and are inserted externally into the larger arteries principally in those places that answer directly to the subjacent adhesions of the semilunar valves. Moreover, as far as we have yet been able to see, these fascicles of fibres seem to penetrate deeply, and to inosculate with the others that bind the abovementioned valves to the internal cavities of the arteries. (*Ibid.*, prop. 32.) Morgagni has openly asserted, that the semilunar valves are strengthened at the very border with tendinous fibres,† and are furnished below with numerous fleshy fibres. This we some time ago observed very clearly in children, particularly in those who had died after attacks of hectic fever, in whom we found these valves in-

\* Ex dexterâ auricularum in sinistrum ventriculorum, alterâ vero e sinistrâ in dexterum, &c.

† See an allusion to this above, p. 372.—(*Tr.*)

creased to the fullest size of which their fibres and the vessels were susceptible. . . . In the *post mortem* examination of children, we found each connexion of two of the valves together, with the aorta, exhibiting a very analogous appearance to the clitoris in female abortions, for raised and crested oblong sutures adhered to the arteries, with which they were united by firm and strong bands of carneo-tendinous fibres, conveniently placed in each of the curvilinear angles of the valves ; the loose borders of the valves being thereby attached to the more solid walls of the arteries. But these fibrous bands are produced further, and joined with the fascicles of fibres that . . . constitute the circular tendons. It is further to be observed, that the semilunar valves have evidently tendinous bases rising a little above the orifice of the heart, and circularly embossed as it were by nature. Each of them likewise is furnished in the middle of its border (as Arantius first remarked, and Morgagni afterwards shewed more clearly in an excellent figure) with certain roundish nodules, which are often cartilaginous and even osseous in old subjects. As they begin to harden, they appear about the size of those tubercles called sties or hordeola, that grow in the corners of the eyes. . . . The tendinous texture of the mitral and tricuspid valves, is more easily shewn than that of the semilunar valves ; since the former go to the columns from nearly cylindrical muscles placed within the ventricles, and after they arise, are dilated and opened out into thin margins, which they who are unacquainted with the ultimate structure of animals, call membranes, although they are true tendons, since they have a carneo-muscular origin, and terminate in white cords, that connect the orifices of the heart with the auricles and their veins. (*Ibid.*, prop 33.) What we have hitherto said of the circular tendons, must also, we think, be understood of the broad tendons, denominated valves. Thus both the mitral and tricuspid, and the semilunar valves, are so formed, that when laid back they allow the blood to pass, but when raised, prevent it from returning. The mitral and tricuspid valves, with their cords and reticular and scabrous bases, (which render nearly the whole internal surface of the ventricles irregular and uneven,) are so directed, that when the cardiac machine acquires a tension, and exercises a degree of impetus at nearly all points of its cavities, . . . they (the valves) most accurately mingle the old cruor or blood with the reflux lymph, with the influent chyle, and with the air, or with those particles that are secerned from the air. (*Ibid.*, prop. 34.) We observe also that certain adipose bands are found disposed upon the coronary artery, and around the four circular tendons of the heart. . . . Nor must we omit to notice certain adipose follicles, which, under the form of cinereous spots, here and there dapple the internal tunics, both in the left ventricle of



strong and adult hearts, and in the beginning of the aorta. When these follicles are pricked with a lancet, we have found them contain fat; and indeed in the body of an illustrious duke, . . . who died of inflammation of the natural and spiritual viscera, brought on by indolent habits and high living, we saw them degenerated into little steatomota. For in the heart of this subject, both within the right and left sinuses, there hung from the lacertuli of the columns, tubercles of a sub-cinereous hue, which on being cut into, were found to contain concreted fat. (*Ibid.*, prop. 35.) The fibres that invest the domes or arches of the auricles, are entirely muscular, and the nearer they are to the doors of the ventricles, the more they assume a tendinous character. In like manner the auricles are larger in the foetal than in the infant heart; so that the right auricle is constantly broader than the left. . . . No one will . . . discover the true causes and reasons of these appearances, unless he lay down the following anatomical postulates. I. That the auricles placed at the sides of the base of the heart, are alternately relaxed and contracted, and when relaxed, are filled with the blood descending from the heads of the veins. . . . II. That the auricles are almost the inverse of the ventricles in their situation, and in the production and direction of their fibres. For the ventricles have their base and tendinous part above, towards the throat, and their apex or muscular part below; while the auricles have their tendons below, or at the base of the heart, but their muscular parts or domes above, or towards the throat. Thus it happens that every time the whole quadricave muscle of the heart is strained and constricted, the auricles are seen to be depressed toward the base, and to descend; and the ventricles to be elevated toward the base, and to ascend; so that the body of the heart, which before was oblong, becomes nearly round and spherical. . . . Finally, we should, I think, remind the reader, that anatomists are well agreed, that the blood moves somewhat more slowly through the vena cava towards the right auricle and ventricle, than through the pulmonary veins into the left auricle and ventricle. (*Ibid.*, prop. 37.) Harvey has observed, that ‘in some men, that is, in those who are of hardy frame and strong constitution, the right auricle is so robust, and so admirably furnished on the inside with sinewy cords and various tissues of fibres, that it seems to rival the ventricles of other subjects; and I was surprized,’ says he, ‘that there should be so great a difference in different persons.’\* And again he says, with still greater clearness: ‘All these parts, (constituting the præcordia,) constantly maintain a proportion to each other, for the more powerful, muscular, and hardy the person, and the more robust, thick, dense and fibrous

\* *Exercitatio Anatomica de Motu Cordis*, cap. xvii.

the heart, the more thick and strong in proportion are the auricles and arteries.\* (*Ibid.*, prop. 38.) Borelli† proves that the momentum of the force of the heart overcomes a pressure equal to 18,000 pounds. (*Ibid.*, prop. 27.)

465. "What Nicholas Steno relates that he has seen in experiments upon rabbits, namely, that the motion of the superior cava, (when even the heart and auricles had ceased to move,) was still kept up by the mere pressure of the finger, and that the auricle was moved by it, we also have taken the pains to observe in the vivisection of horses. . . . For as both *venæ cavæ* in the horse are white, and as solid in appearance as the aorta in the dog, their motion is better seen than in other animals; provided that as soon as the sternum is removed, the pericardium be laid open. For in this case, the vena cava is sometimes found still moving spontaneously, or if not, the application of the warm fingers, or the warmth of the breath, is sufficient to restore it in a short time to its natural temperature and motion. Sometimes when only punctured with a needle or with the point of a lancet, the intermitted motion is again renewed: and when the experiment succeeds, the cava (moving like the intestines) makes reciprocal peristaltic constrictions and vibrations toward the heart four or five times, while the right auricle performs a single contraction only once. But what we have stated of the vena cava, during vivisections, ceasing from all motion, and recovering its beats when pricked with a needle, or stimulated by the application of a warm body, takes place also equally in every part of the heart, in the auricles as well as ventricles; a single prick, or the fresh contact of a warm body, being sufficient to cause irregular palpitations and fluctuations there also; provided always that the heart has not grown cold and stiff. . . . During experiments made upon rabbits, in the month of June, three hours after they had been opened, and when the motion of the auricle had ceased, we saw the cava still moving, and when its branches were tied, and blood was let out through a puncture in the right ventricle, the motion of the two *cavæ* within the ligatures immediately ceased. But as soon as the ligatures were loosened, and the blood was again admitted, we plainly saw the usual motion return in the branches of the *cavæ*, and this, both above, and below towards the right auricle. . . . We ought not to omit to mention, that in the vivisection of fowls, we saw a vermicular motion in the branches of the cava frequently recurring, followed at length by a slow contraction, or fluctuation, of the ample right auricle and ventricle, although there was no spontaneous stroke or pulse in the left auricle; and when the

\* *Ibid.*, *ad fin.*

† *De Motu Animalium*, par. 2., prop. 66, 67, 73.



left ventricle was laid back, we could observe no motion in its posterior wall; although the segments of the heart moved when punctured with a needle; a sufficient proof, that the occasional cause (as they say) of spontaneous tension in the right auricle and ventricle, consisted in the powerful pressure of the blood, which was urged towards the right chambers of the heart by the branches of the cava peristaltically contracting. . . . Nearly all the four kinds of birds,\* have branches of the vena cava, (just as of the aorta,) that open into a very short trunk, or as it may rather be considered, into the ample vestibule of the right auricle. In fowls, if the vivisection be rapidly done, we see as distinctly as possible a motion towards the auricle not only in all the branches of the cava, but also of that coronary vein that runs longitudinally from the cone (I mean the apex) towards the base of the heart, so that the concussion of its tunic seems to begin from the apex, and to continue onwards to the base." (*Ibid.*, prop. 56.)

466. STENO. "In a female rabbit . . . dissected in August . . . I made various observations touching the motion of the auricles and cava particularly. Thus while the right auricle was beating seldom and slowly, I saw at length a motion of the cava, both in the right and left branches, and after two or three pulsations of the cava, the auricle moved once, but not always in the same way: for sometimes the motion crept in the border of the auricle, from the inferior corner toward the superior; sometimes the same border was moved in the contrary direction, or from the superior corner to the inferior; sometimes when the border was entirely at rest, a contraction was observed in the middle plane as it were of the auricle. (In the heart of the pigeon I have also seen a motion proceeding from one corner of the auricle to the opposite one.) When the three branches of the cava were tied, and all the blood that was within the ligature, in the cava and right auricle and ventricle, was let out through a little opening made with a fine needle in the bottom of the right ventricle, all motion ceased at once, and one would have said that the whole of the parts were dead. But this state of rest did not continue long, since the fresh blood issued from the veins of the heart, and slightly distending the collapsed tunics, produced a fresh but slight motion, which was however conspicuous in the cava alone. Nevertheless, when the ligatures were removed, and the blood could freely return to the heart, the motion of both the cava and auricles was restored immediately. . . . In a young cormorant . . . about two hours after the breast was opened, and when the motion of the heart

\* Perhaps Lancisi is here alluding to the birds used in his own and Steno's experiments:—(*Tr.*)

began to languish, the beats of the auricles as well as of the cava could be clearly distinguished from that of the heart: in fact, the motions of all three were distinct in point of time. But when the heart stopped, the part of the auricle nearest the vena cava survived for a long time; and when the auricle also was quite motionless, the cava alone beat below the heart, exhibiting two entirely distinct motions, one of which was seen on the outside, in the remoter part, the other on the inside, in the part next to the heart. What most excited my surprize, as I have not observed it in any other subject, was the circumstance that when the right ventricle was laid open, and emptied of blood, a motion still continued in the coats of the vein, although now completely collapsed, and the transverse fibres, one after another, were slightly elevated thereby, so as to present the appearance of a thread carried transversely over the vein, and proceeding towards the heart: this motion had not ceased at two o'clock in the afternoon, although I began the vivisection at nine o'clock in the morning." (*Thomæ Bartholini Acta Medica et Philosophica Hafniensia*, vol. ii., an. 1673, n. xlvi. § 9, 11, p. 143—146.)

467. According to the observations of several writers, if the hearts of birds, frogs, and other animals, be pricked with any pointed instrument after death, or even after being cut in pieces, they will in a certain manner still contract. The apex of the heart appears to be a very moveable part, as also the right auricle particularly, which beats on being touched with a needle, and sometimes takes on a peculiar vibration; one portion frequently not vibrating with the portion contiguous to it, but the vibration sometimes following in another and remoter part. And a constrictile action may likewise be excited simply by warmth, breathing upon the part, or handling it between the fingers and palm. The motion of the heart may to a certain extent be recalled after death by throwing blood, or warm water, into the vena cava, or into the jugular or subclavian veins, or into the thoracic duct. The heart may be easily made to palpitate by agitating the vena cava near the auricle: in which case the auricle begins to palpitate, and soon after the ventricle also. And it has been observed, that where the current of blood through the lungs is interrupted, the right auricle has palpitated once, twice, thrice, or even five times, before the ventricle or heart has pulsated once. But we have no room for further extracts; those given already are sufficient for our purpose.



#### INDUCTION.

468. BEFORE we attempt to trace out the proximate and remote causes of the motion of the heart, it is necessary,—in addition to what has hitherto been said respecting the blood, the arteries and veins, the primitive structure of the heart, the proper and coronary vessels of the same, and the foetal circulation,—that we should enquire into the cause of the action of the nerves, as well as of the ganglia generally ; and into the cause of the action of the intercostal nerve and par vagum, specifically ; and into the cause of the action of the great cardiac plexus, and the nerves that depend upon it, particularly ; and moreover into the cause of the action of the muscles ; for the heart in all respects is a muscle.

After a due consideration of these subjects, we shall learn, that the proximate cause of the heart's diastole, is the continual pressure and action of the blood of the two venæ cavæ upon the right auricle ; and that the proximate cause of the heart's systole is the extension of the nervous fibres : so that when the blood acts, the nervous fibre yields ; and when the nervous fibre acts, the blood yields.

The cardiac machine is so constructed, that its alternate motion depends upon, and is determined by, the auricles, and particularly the right auricle, as its wheel and lever ; consequently upon, and by, the intumescence of this auricle, when the blood presses, acts, and flows in ; and upon, and by, its detumescence, when the nerves are extended. All the other

parts are so mutually connected, that whichever comes into motion, contributes to its reciprocation. Consequently each, together with the whole, is kept in such perfect equilibration, that the smallest thing inverts the hinge of the motion, and the resistance, which in the natural state is very slight, is easily overcome.

Again, when the same subjects are rightly considered, we learn what are the remote efficient causes of the heart's motion, namely, that the lungs, the cerebrum, the medulla oblongata, the medulla spinalis, and the cerebellum, are such causes. The lungs, since they admit and transmit the blood of the right side of the heart, and keep the præcordia in the universal motion. The cerebrum, since it propels its blood towards the jugular veins by its own proper force, and sprinkles into it the spirituous fluid, and acts moreover upon the muscles of the body. The cerebellum, since it rolls down the blood, also by its own proper force, and so from a living fountain, into the superior vena cava; and fills and animates the cardiac nerves, and the nerves of the arteries and veins, with spirituous fluid. The medulla oblongata and medulla spinalis, since they transmit the blood into both venæ cavæ, and through the azygos particularly, into the superior vena cava. And it is not necessary, that the moments of animation in any of these parts should coincide with the alternate moments of the heart.

Since then these are the remote efficient causes, it follows, that the motion of the heart may be continued for a time without the assistance of any of them; but this time will be longer or shorter in proportion as the abovementioned bodies are in the series and connection of causes: in fine, just so long as the nervous fibres of the heart can be maintained in their integrity and power of acting, to preserve them in which is the peculiar office of the cerebellum; and so long as the blood can be poured from the living fountain into the vena cava.

From these grounds, in connection with those laid down in



our former chapters, we may infer the cause of the variation of the pulse. The causes of it, in general, are internal and external; both of which classes may be further subdivided into natural and preternatural. But the doctrine of the pulse is the last that can be given and completed as its importance deserves.

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469. *Before we attempt to trace out the proximate and remote causes of the motion of the heart, it is necessary,—in addition to what has hitherto been said respecting the blood, the arteries and veins, the primitive structure of the heart, the proper and coronary vessels of the same, and the foetal circulation.*—These are nearly all the subjects that belong to the particular experience by which we gain instruction respecting the heart's motion, and without which we in vain aspire to a true knowledge of it. To understand this motion, and trace it up to its causes, is a work of no little perplexity, and one which may well enlist our best attempts to solve it. Particular experience, or that busied simply about the heart, will not be of much assistance; we must also know the intimate relations of the heart, and its primeval state; and indeed, in general, everything whatever that causes the animal kingdom to live and move: in short, we must possess a general anatomical knowledge (n. 12—16). The reason why so many of the learned have entertained different opinions on the one point of the origin of this motion, is, that they have proceeded and judged from particular experience alone: but these opinions I forbear to detail, because I am resolved to be contrary to no one, but simply to fix my attention upon data and facts, and to follow where I see the truth, or the cause supported by experience and reason.

470. Meanwhile, the nature of the *blood*, of which we treated in Chapter I., must be shewn before we can demonstrate the cause of the heart's motion; for the heart is framed for the blood, and appropriates to its own little arteries and fibres the purest, spirituous, simple, recent blood,—its first-coming guest,—in order that its life may have precedence of that of other organs (n. 453—456). Again, before we can understand the

motion of the heart, we must know how the *artery* acts, and how the *vein* acts; of which subjects we spoke in Chapter II. For the heart is intermediate between the two, and thus between the motions, or modes of action, of the two. For the venous blood acts on the heart, and the heart acts on the arterial blood; so that the right side of the heart is the very goal of the venous blood, and the left side of the heart is the very starting-place of the arterial blood, after it has evacuated the lungs. The knowledge therefore of the heart's motion depends upon the knowledge of both these subjects. The knowledge of the *primitive structure of the heart*, treated of in Chapter III., must also precede the knowledge of its compound structure. The condition of accidents and essentials comes successively, and from the nature of simples: and therefore whoever is desirous to understand causes, should commence from the simple, to which however he must first allow himself to be led analytically, by means of experience, from compounds. But to understand the heart's motion, we must next have a knowledge of the *primeval circulation*, spoken of in Chapter IV. But especially of the *proper vessels of the heart*, the subject of Chapter VI; for these vessels are what lead the blood directly into the motive fibres, or the muscle, of the heart, and hence excite it to motion. But even after a knowledge of these subjects, we are only on the threshold of the enquiry; for all we have hitherto mentioned, belong only to particular experience concerning the heart, however widely they may seem to extend. For there are remote as well as proximate causes of the heart's motion; as Lancisi admits. "I would wish it to be carefully borne in mind," says he, "that in discussing the structure and motion of the heart, I, for my part, have not endeavored to investigate or open any but the proximate and purely corporeal causes of their astonishing phenomena, although I tacitly admit and grant, that another principle of this motion may be found, far higher than the body, and from which as a principal, yet remoter cause, it derives its origin." (*De Motu Cordis*, &c., præmonitum, p. 1.)

471. *That we should enquire into the cause of the action of the nerves generally.* For the motion of the heart, as well as of the whole body, depends upon the brains, and consequently upon the fibres of the brains. But neurology itself is a science of



vast extent, and not to be properly laid down unless we begin from principles: we must come to it as it were from above, descending by degrees; that is to say, after we have understood the cortical and medullary substances of the brains; from which all the nervous substance descends, as from its hemispheres. We cannot then enter into this science at once, because it lies too deep under other sciences.

472. One thing only should be premised in reference to the particular subject we are now considering, or to the motion of the heart; namely, that the nervous fibre, regarded in its simplicity, cannot be better compared with anything than with the artery; for the artery of the brain is continued into the medullary fibre through the medium of the cortical or cineritious spherule, so that it may without doubt be concluded, that the fibre is an artery, by way of eminence, or an artery in a superior degree, as I have often pointed out above. The comparison, if carried out, shews that each, namely, the artery and fibre, springs from a heart of its own; the artery, from the common heart of the body; the fibre, from the little heart or corculum prefixed to it; that is to say, from the spherule of cortical substance, which is expanded and compressed like the great heart of the body, or more properly speaking, animates. Also that each, the fibre as well as the artery, conveys its own blood; the fibre, the simple or spirituous blood; the artery, the compound or material blood. And that each expels this its blood from its heart to the ultimate boundaries; the fibre, to wit, expelling it into the blood-vessels, through which, after passing through the great heart, it returns again into the principles and fibres (n. 152): but the artery, at its point of termination, expelling its blood into the veins, and so sending it again to its heart. That both the artery and the fibre resemble a continued heart; the fibre, because it promptly forwards the fluid it has received, to the uttermost boundaries; and the artery, because it does the same with regard to the red blood. That each is formed with a view to the undulation or modification of its fluid; the artery with a view to the undulation of its blood; the fibre with a view to the modification of its liquid; the artery and the fibre, undulation and modification, corresponding to each other according to degrees (n. 169—174). That each, when intrinsi-

cally expanded by its liquid, is both dilated and elongated (n. 228—230), and so exercises its contractive and expansive force. That each has muscular action; the fibre, because it is a simple motive fibre, or a fibre of the first degree; the artery, carrying the purer blood, and particularly the conglomerate artery, because it is a motive fibre of the second degree; and the artery of the red blood, which is further complicated, because it is a motive fibre of the third degree; as an entire muscle is, of the fourth degree. That the artery is nothing but a compound fibre; for the nervous fibre winds round the arterial vessel in a perpetual circle, just that the fibre may pass from the superior degree to the inferior, while it becomes the artery, or the motive fibre of the fleshy muscle; for the purpose of being enabled to act conformably upon the fluid of that degree, or upon the blood. Therefore there is no truly vital solid in the whole body but the fibre; and there is no truly vital fluid but the spirituous fluid in the fibre and in the blood, and which is the one only animal substance: so the body is nothing more than the appendix of the brains, for their's is the fibre and spirituous fluid, or whatever lives in the body. The fibre, with its enclosed spirituous fluid, assumes every affection that the little heart or cortical spherule prefixed to it, receives; almost as the artery with its blood receives every affection that the heart impresses upon it, as is manifest from the pulse: so that the fibre has the same state as its parent brain. The reason of which is, that in elastic substances nothing perishes, but the state communicated to one is communicated to all (n. 100, 101). Almost the same rule holds good analogically of the red blood, in which the same qualities exist, but more imperfectly according to the degree of composition (n. 102). Meanwhile all nerve, while it is produced in its natal soil, is formed with a view to ultimates, or regards the use that it is to afford in extremes (n. 251). For this reason it is various in its maniples and fasciculations; and it comes forth hard or soft; and as it runs on, it exercises processes of exuition and separation to suit it for uses in intermediate things also; and finally, in all the ultimates, it falls almost into simple fibres, just as it was in the primes; and into more simple fibres when it has to receive sensations; into less simple fibres, when it has to attempt and effect motion: therefore it is pretty nearly similar



to itself at both extremes ; and in the intermediates, or along its course, it is a conglomeration, or properly a nerve. But it were useless to carry the parallel farther ; for the comparison throughout presupposes the existence of a spirituous fluid, and the permeability of the simple fibres ; of which subjects we shall speak decidedly in the Parts on the Brain. Here we only add, that if any one deny these things, because the eye in its dullness cannot reach them, he deprives of their causes all the effects that nature operates in the animal kingdom.

473. We observe in general with regard to the nerves, that the specific function of any nerve cannot be explored, unless we explore also at the same time the office of the muscles that it enters and perforates ; the office of the glands that it moves ; of the nerves with which it communicates ; and of the arteries and veins that it comes in contact with : all which must be collected in one sum ; then the compound and simultaneous action of all, and the simple and particular action of each, must be considered. For every nerve represents an equation of several numbers or syllables, as in the algebraic analysis, and we are ignorant of its value, until it is resolved into analogies and ratios, or into various forms of subordinate equations. And in the unanimous body, all the actions possible in any one subject, are represented by the nerves, and subsist as it were in equation, so long as they do not represent any distinct action. If then an action be like an equation, and each fibril, or texture of fibrils, be like a number or ratio entering into the equation, it is evident that the twig of a single nerve can be used as a part or ratio in innumerable actions (n. 15) ; for whether we speak, sing, cry, eat, cough, gape, sneeze, fight, or embrace, the twig of one nerve can take some share in all these actions, although every nerve has its own proper function. But if we would resolve the whole of this natural equation, we must have a knowledge not only of every nerve specifically, but of every nerve generically also. The trunk is analogous to the general ; the branches derived from it, to the particulars under that general ; while all are universally under the most general. Meanwhile, in surveying the astonishing connexion of all parts, scarcely any feeling remains but mere wonder. To consider them severally would be to write volumes. Nature is always in

her art, and in the rules of her art; and in one moment she brings and pours forth results exceeding our capacity, in such profusion, that ages cannot exhaust them. Yea, the analytic and differential calculus itself is poor in unfolding these series of nature. It falls at once into surds and inextricable questions, and only involves the relations that reason *does* see clearly, in Gordian knots, as any one may find upon making trial.

474. *As well as of the ganglia.* It is from the ganglia principally, as from new stations, that the nerves, as they pass from the brains to the body, are derived into the præcordia, and into the parenchyma of the heart. The intercostal nerve especially, in the course of its descent, exhibits occasional ganglionic enlargements, which are termed ganglia, ganglions, ganglioform plexuses, olivary bodies, tumors, or nodes of the nerves. But let us begin with a description. These bodies, usually oval, have tendinous vertices, or heads and tails like muscles, (for example, the semilunar ganglions); they are larger or smaller, as the hordiform ganglions, or those of the spinal nerves; they vary in consistency, color, volume and number; they arise from the confluence of several nerves, but are planted on one trunk principally; they are supported and invested by arteries, veins, nervous, tendinous and fleshy fibres, and by several membranes; thus they may be considered as fulfilling the office of so many ministrant cerebellula in the places where they are set; moreover they consist of a mixture of cineritious and medullary substance. The cardiac nerves themselves, as already observed, and as we may see from the plates of Lancisi and Vieussens, proceed for the most part from such ganglia, and principally from the great cervical ganglia of the intercostal nerves on both sides. The highest of these ganglia on the left side gives out from its bosom a large trunk toward the præcordia, and a considerable proportion of the others also is spent on the cardiac plexus. Now as it is our present object to explore the action of this plexus, we must begin our enquiry from this point. The highest cervical ganglion on the left side, from which as its genuine beginning, and also from an almost similar ganglion on the right side, the intercostal nerve proceeds, and determines itself both upwards and downwards, may serve as the exemplar for all the rest. This ganglion, according to the exquisite dissection instituted by



Lancisi, and the minute description which he has given, is enclosed within three membranes, a little increased and thickened by an accession of fibres.\* The exterior of these membranes loosely invests the ganglion, as the tunica vaginalis testis invests the testes, and the enclosed body may be squeezed out like a kernel by compressing it between the fingers. Its tissue is made up externally of red fibres; internally it is moistened with a light lubricating fluid, like that of the pericardium. The other tunic invests the ganglion still more closely, and consists of tendinous fibres, but more solid and complicated. The third membrane, called by Lancisi a circular tendon, is composed of a tendinous substance strongly united to the body of the ganglion, and has its fibres continuous with fleshy fibres. So that the whole ganglion is formed principally of two tendons; 1, of a single external tendon, consisting of the two outermost membranes, and of the little nerves diffused through them; which tendon not only covers the whole mass of the ganglion, but also enables it to exercise muscular action force. 2. Of another tendon, which descends through the middle axis of the ganglion from the head to the tail, and gives off penniform fibres. In this ganglion, boiled and stripped of its tunics, Lancisi discovered on the outside a kind of nervous rete closely implicated with its membranes, and under it fleshy fibres running in beautiful order from top to bottom, as in the rind of a melon divided by furrows into equal segments. In addition to this, innumerable fibrils, united with the internal tunic, emerged from the intermediate commissures of the fibres, and which were torn away as the ganglion was stripped of its membranes. The superior vertex of this ganglion is attached by nerves and membranes to the fulcra of the vertebral and cranial bones. Into this ganglion, as indeed into the others, not one only but several nerves are admitted, some of which run in straight by the vertex, others transversely at the belly and sides, others insinuate themselves obliquely; most of them reach as far as the internal substance, but some are dispersed solely through the membrane. Such as penetrate to the internal substance, seem to be slightly tinged with a blood color, but the rest are white. The blood in the internal substance is derived from the trunks of the neigh-

\* *Dissert. de Gangliis Nervorum*, fig. 2, 3, 4.

boring arteries and veins, and entering the ganglion, together with a farrago of nerves, contributes, with them, to make up its bulk; a bulk which nevertheless always appears greater than is proportioned to the various bodies and vessels that enter it. The nerves that issue from this ganglion proceed in different directions; for instance, to the pharynx, larynx, tongue, membranes, trachea, bronchia, nay, even to the carotid artery, the aorta, and jugular vein, and to several muscles; but the nerve that proceeds toward the præcordia, descends between the mediastinum and the pericardium.

475. From the evisceration and anatomy of this principal ganglion of the intercostal nerve, we decidedly learn, that the ganglia in general are constructed for the purpose of promoting the progress of the nervous liquid and spirituous fluid. For the fibres in the nerves are so compacted within their tunic, and the fascicles of fibres within theirs, that unless they are unfolded and relaxed on their way, they cannot pour forth their liquid in that abundance which the most active muscles are perpetually requiring; such muscles, for instance, as those of the heart, trachea, larynx, pharynx, and tongue; nay, of the aorta, carotid artery, and jugular vein; all of which are in a state of perpetual activity, and require a continuous and unimpeded flow of blood, inasmuch as their life consists in their action. Not indeed that the above-mentioned fibres and fascicles deposit aught of their liquid in the ganglia themselves, or terminate in them, and run out from them again as from new stations; but after being previously constricted, they here relax their bands, and enjoying a freer expansion, suffer the fluid to be propelled onwards, and at the same time themselves propel it. That they do propel, is manifest from their muscular character; that is to say, from their membranes, their blood, their fleshy fibres, their tendinous extremities, their belly, and their oblong figure; so that when they contract, they draw upon the continuous nerves, and when they unfold, they relax these nerves; and indeed the whole nerve distinctly, the fascicles of the nerves distinctly, and the fibres of the fascicles distinctly; for the outermost envelope surrounds them loosely, and there is a nucleus within, through which the fascicles run out in different ways, though for the most part in a right line, and which is likewise



invested with a muscular tunic. There are small meshes, or as it were retiform plexuses of fibres, that either creep in one integument, and there fold themselves up, or else intervene between the integuments. Hence the little ganglia are themselves vehicles of nervous fluid, and are consequently auxiliaries of the cerebellum, medulla oblongata and medulla spinalis, without which the extreme fibres, whose activity is perpetual, would soon be destitute of their vital fluid; a circumstance to which the cardiac machine would be especially liable, acting as it does unweariedly, and never permitting its muscle to subside into rest.

476. But in order to explore all the uses of the ganglia, we ought to enquire into every detail respecting them; into all the nerves, arteries, and veins that enter them; and into the mode in which these run through the Gordian knot: and into those that pass out from them; and what muscles they enter; and then into the general and particular action of the muscles, inasmuch as it proceeds from the nerves of the given ganglion; which action again should be compared with the origins of each nerve, and with the use and office it is dedicated to from its very infancy (n. 473): an investigation which would be exceedingly complicated, unless all things were considered in order. But such an enquiry belongs rather to neurology associated with myology, and to both as applied to the natural and voluntary actions of the body and members. Meantime it is evident, 1. That the ganglia serve as auxiliaries and vehicles for moving the nervous fluid onwards. 2. And in fact they distinctly move onwards that which flows between the fascicles of the fibres, and that which flows between the fibres, and that which flows in the fibres (n. 157). 3. And by a proper muscular force, and a force analogous to muscular, they drive from point to point the fluid that intervenes between, and the fluid that traverses, the fascicles and the fibres; and thus perform an assistant function to the brains. 4. They receive the reflex motions both of the entire nerves, and also of the fascicles, and extinguish these motions, to prevent them from penetrating up to the brains, and disturbing the principles; for the ultimate envelope surrounds them loosely, so as to dull and restrain the impetus of the disorderly nerve. 5. They reduce the various, and even

subordinate natural motions, to one universal motion, which is that of the brains. 6. They finally combine into a single centre of action, the several nerves contributing to any common or particular action, so that out of this centre of action the nerves are enabled again to emanate with a similar force and animus; at least in respect of the fluid and life of the nerves that produce the very action in the muscles. But under what form of society the nerves pour forth to the field of this action, and how they mingle so as to conspire, is a secret which no acumen of sight can penetrate, and which can be ascertained only from the extremes where the nerves again unfold themselves into fibres; in short, from the mutual and distinct survey of effects.

477. *And into the cause of the action of the intercostal nerve.* A specific knowledge of this nerve is requisite, for it, together with the par vagum, has the government of the heart. From nearly all its ganglia placed in the neck, it sends considerable branches, some to the pericardium, some to the great reticular plexus, and distributes another entire [branch] over the ventricles of the heart; so that the heart seems to be entrusted to its guidance particularly. Wherefore, without a previous description of it, and an understanding of its mode of action, we cannot treat of the motion of the heart from the ground of causes.

478. The intercostal or great sympathetic nerve, constantly increasing from nerves passing to it out of the spinal marrow, is supposed to derive its origin from the fifth and sixth pairs of cerebral nerves. Whether it arise from these, or whether it terminate in them, it is well ascertained that one, two, or more threads ascend at the inside of the sixth pair, or that a fascicle of several issues forth obliquely, and contrary to the flux of the fibres. But the mode, condition, obliquity, and number of the inosculating filaments, varies according to the various characters of subjects. Eustachius places its origin or end in the sixth pair alone. Vieussens, Ridley, Heister, Willis, and other penetrating anatomists, derive it from the fifth and sixth pairs conjointly. Indeed it is evident, that neither the fifth nor sixth pairs, when traversing the receptacles of the sella equina, dispose themselves to form the intercostal nerve; but that the latter, by sending out slender cords and slanting roots, connects



itself with [those] nerves above. Morgagni “observed three nerves descending on the left side, one creeping up by the posterior part of the carotid artery where it enters the receptaculum, the others by the anterior part, and running into its foramen” (*Advers. Anat.* vi., *Anim.* 24); so that the nerve is reflected round the posterior parts, lies under the carotid, and creeps within its proper and adscititious coat, and so passes into the cranium. It comes out under the Eustachian tube, between the styliform process of the occiput, and its articulation with the first cervical vertebra, and then passes over the foramina through which the jugular veins on one side, and the ninth pair of nerves on the other, leave the cranium, or where the internal carotid enters it.

All the spinal nerves, except the first and the three last, immediately after coming from the spinal marrow and vertebræ, present little tumors or ganglioform granules, which transmit short twigs or cords to this intercostal nerve; in the neck, a single twig comes from each little ganglion; in the thorax, two twigs, one from each side of the ganglion; only one again in the lumbar region. Of all these the great and common nerve is made up, and seems everywhere to be gathering new forces and origins, as a river receives tributary streams. Thus arising, it continues its course on each side, well supported, down the vertebral column, beside the transverse apophyses to the last lumbar vertebra, and then in front of the sacrum. During this passage, it expands here and there into ganglioform bellies, as it did immediately under the cranium, into one on the left side higher and larger than the rest, which is its superior cervical ganglion, and has another similar ganglion corresponding to it on the right side, but which in many subjects inclines [*cedit*] to the left. Opposite the sixth or seventh cervical vertebra, this nerve again makes a similar station, and on both sides enlarges into a ganglioform plexus, called the inferior cervical; as soon as it reaches the dorsal vertebræ, it has another plexus called the thoracic. From this point it descends without any swelling or diverticulum, into the abdomen and as far as the loins, where it again begins to expand in the lumbar intervertebral spaces respectively, as it were into barley grains, ten on each side; but

according to Eustachius, it forms one largish plexus near the kidneys before it forms the smaller plexuses.

The cervical ganglion of the left side, occupying the nerve about its entrance into the cranium, stands at the head of the family of ganglions. It receives, in the midst of its belly particularly, various threads from the whitish nerve of the par vagum, which issues out of the cranium through another foramen. It gives out from itself and its belly and envelope, several as it were tendinous twigs to the muscles, arteries and veins; and itself lies between the carotid and jugular vein; it likewise gives out a few others to the descending branch of the par vagum. This place seems to be the womb and native ground of the intercostal nerve, for here the eighth pair unites with it, and twigs of the fifth, sixth, ninth, and tenth pairs come to it from above, or from the medulla oblongata, and branches of the first, second, and third cervical pairs from below, or from the medulla spinalis. All the other spinal nerves communicate with it by branches from their little hordiform ganglia, as also from the muscles, their cords being first consociated by wonderful plexuses, one portion of these cords running into the ganglion, and another portion running out of it. Here by a network of nervous threads intertwined with blood-vessels, it takes possession of the carotid artery and jugular vein. Nor does this nerve begin to attain its peculiar character, till it arrives at this place immediately under the cranium, where the vertebral column commences. Hence as soon as it emerges from this olivary ganglion, it runs upwards through a foramen into the cranium, fixing tooth and nail upon the carotid. Thus it communicates with all the nerves of the head, as with the first, second, third, fourth, and seventh, by means of the fifth and sixth; with the eighth, ninth and tenth, by means of its ganglion; and with all the nerves of the body, or with those of the medulla spinalis down to the os coccygis. Lancisi divides this great general nerve into a superior, inferior, and vertebral portion. So far of this nerve generically: it would be tedious to pursue it through all its windings in the provinces of the body.

479. From the foregoing description it is evident, that this nerve has the universal charge of the body; in that it



transfuses and dispenses the spirituous fluid and nervous juice everywhere, so that both the nerves and muscles, and the veins and arteries of the body, and even of the head, are never destitute of it, or consequently of their activity and life. And this nerve can never fail of this fluid, because it has a fresh origin at every point of the spinal marrow, and is kept in the stream of the animation of the brains and medullæ. Which is the reason why, wherever any natural motion prevails, it associates with the *par vagum* to form retiform plexuses; and especially about the heart, into which it pours nerves abundantly from its ganglia. Thus it appears, that this nerve arises from the *medulla cerebelli*, and is the vicegerent of the cerebellum in the body. But to come to details.

480. This nerve has the universal charge of the body.—For it approaches and enters all the viscera of the body, both in the epigastric and hypogastric regions; and even the veins, great and small. And either it invites the nerves into some of its ganglia, or associates them to it in some reticular plexus, or otherwise joins company with them, or else climbs up over them. From which it follows, that it exercises some universal charge; and for this reason it was that Winslow termed it the great sympathetic nerve. It appears to have this charge,

481. In that it transfuses and dispenses the spirituous fluid and nervous juice everywhere, so that both the nerves and muscles, and the veins and arteries of the body, are never destitute of it, or consequently of their activity and life.—To this office it is devoted: as we may infer, 1, from its multiple origin; for it is born from almost as many wombs,—its one stream arises from as many fountains,—as there are foramina in the *vertebræ*. Hence it is ever fresh, and ever swift of flow; hence when it loses one head, another surviving branch supplies the trunk; lest any plexus or muscle dependent upon it should die; as experience teaches. 2. From its swelling out, during its course, into so many ganglia, in which it unfolds its fibres, in order to excuss the fluid with increased certainty and expedition from point to point, and which ganglia

it invests with muscular power, in order that they may act in lieu of the brains in propelling the juice. 3. From its running with its branches to those spots especially where the greatest vital motion is going on, as for instance, to the larynx, pharynx, lungs, heart, diaphragm, stomach, intestines, mesentery, kidneys, liver, &c., and continually to the most active veins and arteries, as to the vena cava, vena azygos, and jugular veins, the aorta, the subclavian and carotid arteries, &c.; so that the muscles of these parts are never deprived of their vital juice. 4. From the manner in which this nerve performs its office, as appears from its conjunction with other nerves, either in retiform or ganglioform plexuses, or simply by anastomoses; to which when it has thus lent its fluid, or rather added itself laterally (n. 567), it often runs out again into other plexuses, to provide all with fluid either out of what remains, or else anew from its origin.

482. It distributes its fluid also into the nerves and muscles of the head and its organs.—In the description already given of this nerve, it is shewn that there is no nerve of the body, and no nerve of the head, that it does not communicate with, and this, visibly, outside the vertebral theca. That it communicates also by contact of some kind with nearly all the nerves of the body, in the spine itself, or while flowing down in its fibres, will be shewn elsewhere from argument founded upon experience. In the meantime we observe, that it communicates likewise with the nerves of the head or medulla oblongata; as for instance, evidently with the eighth, ninth and tenth pairs by means of the uppermost ganglion; and with the first, second, third and fourth pairs by means of the fifth and sixth pairs. For the fifth pair of cerebral nerves performs an office in this superior region almost similar to that which the intercostal performs in the lower region, and acts there as the great sympathetic of those nerves, and the regulator and dispenser of the liquids. I mean its *portio dura*; for it goes to all the nerves of that region, because it goes to all the organs of the senses. This fifth pair arises from the *tuber annulare*, which is a thalamus made up of fibres from both the brains; and it passes immediately after its origin into a little ganglion, in order everywhere to dispense the received liquid in the same manner as the intercostal nerve dis-



penses it in the body. Into this nerve, and at the same time into the sixth pair, flows our intercostal nerve, but not *vice versâ*: hence through the medium of these it is able to communicate a large abundance of its liquid to all the nerves of the head. But this general nerve of the head does not communicate with the intercostal nerve of the body, because it could not join with this nerve without a loss of the liquid designed for the most noble organs of the senses. That the intercostal nerve flows into the fifth and sixth pairs of nerves, but not *vice versâ*, may be inferred from the fact, that it is not continued from them, but runs into them at a very acute angle, being like a graft upon them; but still more evidently from this, that if the action of each of these nerves be granted, or the extension and remission in accordance with the animations of the brain, (as surely must be the case in that region,) then were they intermarried in any other manner, one nerve would extend simultaneously with the other, and they would reciprocally recede and separate, whereas they now reciprocally approach.

483. And this nerve can never fail of this fluid, because it has a fresh origin at every point of the spinal marrow, and is kept in the stream of the animation of the brains and medullæ.—For every time the brains animate, they drive out their fluid into the fibres and nerves; much as the heart, at every systole and diastole, drives out the blood through its vessels; for every fibre has a cortical spherule prefixed to it, to serve as a little heart (n. 177), and which, as it animates, or is expanded and constricted, drives out its fluid through the fibre continuous with it; hence into all the fibres generally, when the brains and the medulla oblongata and spinalis animate generally. We intimated above (n. 283), that this animation is synchronous with the respiration of the lungs, although we have not yet proved the point as its vast importance demands. That the intercostal nerve is placed, so to speak, in the stream of this animation, is very clear, 1. From the multiple origin of this nerve, which if it is not actually born from all the fibres of the spinal marrow, yet it arises from them after contact; for twigs are sent out to constitute it, from all the vertebral foramina: hence if it derives anything by this way from the spinal marrow, it must likewise be in the stream of its motion, and if so it must also be in that

of the cerebellum and cerebrum ; for the two streams are coincident ; much more must this be the case, if the spinal marrow be as it were the appendix and prolongation of the medullary substance of the brains, to which it associates its own proper medulla excluded or born from its own cineritious substance ; therefore that which is the cause of the cause is the cause also of the thing caused. 2. And the more so, as we shall soon undertake to shew, if the intercostal nerve originates from the cerebellum, or if a medullary process of the cerebellum, descending along the spinal marrow, after contact with the fibrils of that marrow, issues through each foramen out of the theca, to constitute this nerve, by which means it is kept in the stream of the motion of the cerebellum, as well as of the spinal marrow. 3. This nerve receives a cord from each hordiform ganglion that lies just out of the foramina of the vertebræ ; into every one of which ganglia the spinal marrow immediately passes with its fibres, its fascicles of fibres, its pia and dura mater, and its blood-vessels. Hence also the action of the spinal marrow passes into the beforementioned little ganglions, and from these wholly into the nerve made up of the cords sent out therefrom : and this, still more evidently in the dorsal region, where the spinal nerves go out, for there it receives two cords from the ganglions, whereas everywhere else it receives from them only one ; the reason being, that the spinal or dorsal nerves act immediately upon the muscles of respiration, or the intercostal muscles, and are thus in the very region where the stream of this motion is, inasmuch as the respiration of the lungs is synchronous with the animation of the brains. 4. Add to this, that its highest ganglion in the neck is attached at one end to the cranium, and this is the ganglion into which the medulla of the cerebellum first flows ; so that the intercostal nerve begins to receive its motion immediately from this point, a motion which is either in the very stream of that of the medulla, or else is in direct accordance with it. 5. That the case is so, might be inferred also from the fact,—that this nerve insinuates itself in various ways into all the branches of the azygos, and into the azygos itself, and entwines them like ivy ; and still more clearly from this circumstance, that the moment the carotid enters the cranium, this nerve at once enfolds it, creeps between the proper



and adscititious coat of this artery as far as the receptacles of the sella equina, nor separates from them except at the base of the brain, where this vessel, hitherto in trammels, it finally delivers free to its moving cause. All this is to the end, that this nerve may be in the same stream of motion as the internal carotid, which suffers itself to be acted on by the brain alone, and by the motion to which the brain disposes it. It may be mentioned also, that this nerve enters the tunic of the jugular vein. 6. Since, therefore, the intercostal nerve is kept constantly in the stream of the motion of the brains, it follows, that it derives from them a large abundance of fluid, which it distributes where necessity requires.

484. Which is the reason why, wherever any natural motion prevails, it associates with the par vagum to form retiform plexuses; and especially about the heart, into which it pours nerves abundantly from its ganglia.—For the par vagum arises from a single root, which is afterwards continued, but not from a multiple root like the intercostal nerve; consequently it cannot transmit through its trunk so large an abundance of fluid, although where too great a motion exists, it will frequently expend more than the due quantity. To prevent this, precautionary means are taken, particularly about the heart, into which the intercostal nerve flows copiously from its ganglia; as the reader will see below.

485. Thus it appears, that this nerve arises from the medulla cerebelli, and is the vicegerent of the cerebellum in the body.—No anatomist indeed, even had he the eyes of a lynx, could by tracing the fibres, give ocular demonstration of the fact, that the cerebellum spends itself on this nerve. We must therefore adopt some other method of proof, or else the truth of the matter will remain in perpetual obscurity. The method I mean, is that of examining the ways that the nerve acts in its extremities, and then comparing them with the distinct characters of the brains. For, 1, it is perfectly well known, that when the cerebrum, or even a portion of the medulla oblongata, is sliced, laid back, or compressed, the vital motions of the body, as of the heart for instance, do not cease; for according to the experience of Vieussens, the heart beats almost as before, (*Neurographia Universalis*, cap. xx. :) but when the cerebellum is cut,

sliced, or compressed, the pulse of the heart immediately stops; proving that the spirituous fluid proceeding to the intercostal nerve is immediately intercepted, and that the nerve cannot receive a fresh supply from either one origin or the other. Thus the cardiac muscle is deprived of the power of action, and consequently dies. The case would be otherwise if the nerve consisted of the fibre of the cerebrum, medulla oblongata, or medulla spinalis, from which, even on the decease of the cerebellum, new life could nevertheless flow in, and the motion of the heart be continued. But this argument only illustrates but does not prove; for when the cerebellum reposes or dies, the spinal marrow also is quiescent, (so close is the connection between the two in most land animals), and thus if the nerve arose from it either, the stream of motion would for a similar reason be intercepted. But, 2, this nerve it is that has the universal charge of the body, just as the cerebellum; the case is different with the cerebrum, which has the particular charge especially of all things, by means of the medulla spinalis and oblongata; hence this nerve has an origin accordant with its nature. 3. And this nerve never approaches the tunics, organs and viscera, that possess sensation, or the muscles that are excited by a previous exercise of the will, except only so far as to communicate its fluid to the nerves of sense, and to those that excite the muscles to action in conformity with the will. Not so the nerves that arise from the medulla oblongata and medulla spinalis. From these circumstances we have abundant evidence to shew, that the nerve germinates from the medulla of such a viscus as possesses no particular sentience, and exercises no particular will; consequently, that it arises from the cerebellum. To enumerate all the viscera and their membranes, all the muscles and glands, to which this nerve goes, would be tedious. I have traced the courses of most of them, but have never hitherto met with any part of the body that it enters for the sake of receiving sensation and producing voluntary motion. For into whatever part it entered where there were motion and sensation, into the same I also found several other nerves of a different family determined, producing this effect; in such cases, therefore, the intercostal nerve entered solely for the purpose of vivifying them with its fluid. This is very clear when we contemplate its different



modes and laws of acting; as in the œsophagus, where the voluntary motion of deglutition is converted into a natural spontaneous motion: and in the larynx and bronchia, whose motions again partake of natural spontaneity; and most plainly in the heart, stomach, intestines, mesentery, arteries and veins, upon all which the intercostal nerve spends itself. Hence we may in a measure conclude without ocular testimony, that this nerve, as well as the par vagum, (of which we shall speak in the sequel,) is the most noble offspring of the cerebellum, and is its vicergerent in the body. 4. If, then, this nerve arise from the fibres of the cerebellum, and those of its first process that embraces the stem of the medulla oblongata above the fourth ventricle and under the nates, and then descends, we must in this case assent to the opinion of Lancisi, who derives the first origin of this nerve from the two protuberances called the testes and nates, (*De Motu Cordis*, &c., prop. 48), where they are connected with the peduncles of the pineal gland. Be this as it may, whether it derive its origin from these fibres, or from others, it originates from such as flow downward. See also n. 490.

486. Before dismissing this nerve, I must explain in general how it and the par vagum associate with the arteries and veins, and reduce them, and all other parts, to the universal motion of the brains. The animal frame, and especially the human, is a machine impelled by most diverse motions, all of which nevertheless return through a certain orbit to their principles, in which they are perpetually terminating, and from which they are perpetually beginning. Hence the necessity of such a number of auxiliary nerves; such a number of intermediate and coöperating causes; such a number of ganglia, particularly in the intercostal nerve; such a number of communications of nerves with these ganglia, and such a number of derivations from them. For a self-moving carriage, like the human body, having so great a multiplicity of wheels, each revolving at a different rate, must either run awry, or upset, or stop, and go on, or have the most desultory motions, unless there be machinery to combine and harmonize its movements. Suppose that a water-wheel turned by a rapid stream sets the machinery of a mill in motion, and that to increase the power, other wheels turned by different streams are added afterwards: the

whole must be confusion unless the skill of the mechanic combine the parts and regulate the whole. It is therefore provided, by means of numerous networks of nerves, numerous cochleæ, corollæ, and webs discriminated by various threads, that all the parts may agree and combine with precision and regularity. Thus every danger is obviated. Hence animal nature never throws out any thread of her tissue at once, or at random, but has always a relation to ends arranged in a premeditated order; and in pursuing her course between two opposites, so holds fast the mean, as never to pass from one to the other except through such a successive series, that differences disappear before she arrives at the opposite; and so she passes furtively, yet harmonically and kindly, to the other extreme. Thus, although she is ever various, yet her variety and contrariety vanish by reason of the similitude between degrees, that is, by means of the proportional harmony between the two opposites, which without the intermediations must entirely disagree. Nothing stands in Nature's way—nothing is difficult to her, as she goes by insensible degrees, proportionally and harmonically, from one extreme to another. For a consociating harmony is always possible, particularly by means of the purer fibres and fluids, which being more perfect than the others, and most distinctly determined, conspire the more to mutual harmony, nor suffer themselves so soon to be led into surds, or disproportional and discordant quantities. How this is effected, appears from the whole fluxion of this nerve: for instance, in regulating the blood-vessels, where it first only touches the twigs and ultimate tunic; next it surrounds and embraces them; leaving both artery and vein as it were unconscious of the agent by which they are acted upon;—it forms at the same time a reticular plexus and mesh, to entoil and entangle the vessel; but nevertheless in such a manner as to give way to the vessel when acting strongly; it afterwards twines in more intimately, and glues itself to the membrane; finally it enters the inmost membrane, and its doors and its bolts. Thus it proceeds from one extreme to another, and no dissension is apparent; and should there be any resistance, it immediately remits the force of the resisting agent into some loose or flaccid cords, or into some ganglion, where all anger and renitency are extinguished; finally it delivers up the artery, released from re-



straint, to the common mover, nor in all this does it wear any other than a generous and kindly countenance. In no other manner can either the red blood or the nervous juice circulate, or the several parts, together with the whole, subsist and grow up amid so great a multiplicity of operations. It is thus that this nerve is the vicegerent of the cerebellum, or rather thus that the cerebellum, by this nerve, applies itself to adjust and consolidate the interests of its kingdom.

487. *And of the par vagum specifically.* The other common nerve that is dispatched from the brains into the regions of the body, to perform a universal work, is the eighth pair, or par vagum. This, together with the intercostal nerve, forms a great plexus, by which it enters the surface of the heart; and it sends branches immediately to the auricles. It is worth while therefore to enquire into the nature of its action; and the rather, since as above observed, the nervous fibre is all in all in the muscle. Let us begin then with a description of this nerve.

488. The eighth pair, par vagum, or nervus sympatheticus medius, arising by very firm fibres and fascicles which are immediately clothed with pia mater, and which are eight in number, or according to others twelve, comes forth under the form of a fascia between the restiform process of the cerebellum, where the latter is in a manner furrowed, about the end of the fourth ventricle, nearly under the tuber annulare, and at the olivary eminences on both sides. The fibres thus coalescing, and afterwards dividing into anterior and posterior, and mounting between the olivary process and the cerebellum, enter the nearest orifice in the cranium, between the occipital bone and the petrous portion of the temporal bone, where the short canal of the lateral sinuses terminates, or where the blood of the sinuses discharges itself into the jugular veins. There they perforate the dura mater, either conjointly in one place, or as two trunks in two or more places, separated from each other by exquisitely thin membranous partitions from the dura mater, or bony partitions continued from the skull; by which they keep themselves from the jugular veins as they are about to pass through the same foramen. When this nerve is going to perforate the dura mater, a little nerve creeps up obliquely from below, arising from three, four, or more of the uppermost pairs of cervical

nerves: this little nerve is the spinal accessory, and becomes the companion of the par vagum within the same tunic: but this in such wise, that from its first union with the eighth pair, it keeps its own fibres bound apart from the others, as also the superior lesser trunk.

The trunk of the par vagum, issuing from the cranium through a large semicircular foramen, together with the spinal accessory nerve and the jugular vein, between the styliiform process, and the articulation of the occiput with the first vertebra, immediately prepares itself for the performance of its peculiar offices, and splits into a superior and inferior trunk; of these, the superior, smaller or first trunk, as soon as it separates from the larger and inferior, winds to the muscles at the base of the tongue, to the pharyngeal muscles, the genio-hyoidei, &c. But the large whitish trunk runs down together with the intercostal nerve between the carotid artery and jugular vein; with which vessels it communicates on the way, by a kind of cellular, filamentary, and membranous sheath. As the trunk of the right side passes before the subclavian artery, it gives off a branch that turns under the artery, and so reascends to the side of the trachea, constituting the recurrent nerve. The trunk then traverses the whole body and all the viscera, wherever any natural motion exists; to trace it therefore through all the mazes of its erratic course, would be in fact to run over all the provinces of the body. This nerve unites in various places by threads and plexuses with the intercostal nerve. And in several places it comes in contact with the aorta, and supplies the muscular tunic of it and its branches with nervous fluid.

There are several plexuses that it forms, particularly with the great intercostal nerve; such as the *pulmonary* or *pneumonic* plexus, which is double, and from which filaments are sent through the whole of the lungs. The *cardiac* plexus, also double; a quantity of filaments from the great cardiac plexus traverse the pericardium, and enter the heart. The *stomachic* nerve or plexus ramifies over the upper orifice of the stomach, and runs in a curve to the pylorus. There are also the *hepatic*, *splenic*, and *renal* plexuses, but more particularly the three great *mesenteric* plexuses, *superior*, *middle*, and *inferior*. The latter of which goes to the membranes lying upon the sacral vertebræ,



to the coats of the rectum, to the bladder, the uterus, the ovaries, and the genital members. We may likewise observe, that the par vagum, together with the œsophagus, passes through the fleshy part of the diaphragm, as does the intercostal between the fleshy fibres of this transverse septum, near the dorsal vertebræ.

489. If we trace this nerve still further, into all the muscles that it penetrates, and if we consider the actions of these muscles separately and conjointly, it will be evident, that

This nerve is the second most general offspring of the cerebellum; for it is sent to all the viscera of the body where any natural or spontaneous motion is going on. For this use the nerve prepares itself from its earliest stages; for it brings out with it as many bundles as there are origins of such motions in the body. But since it descends on both sides as a single trunk, it is necessary that everywhere, and particularly in the plexuses, it should be associated with the intercostal nerve, that it may be recruited, whenever occasion demands, with spirituous fluid, as we more particularly find to be the case about the auricles, ventricles and proximate arteries of the heart.

But to come to particulars.

490. This nerve is the second most general offspring of the cerebellum; for it is sent to all the viscera of the body where any natural or spontaneous motion is going on.—For it has general charge of the body, just as the intercostal nerve, or as the cerebellum itself; it presides over those natural or spontaneous motions, as they are called, that do not flow into act from any previous reason and determination of the cerebrum, such as those of the heart, stomach, intestines, mesentery, spleen, liver, kidneys, bladder, uterus, and some of the genital parts; it also presides over the motion of the lungs, which is mixed, or whose origin is both spontaneous and voluntary; as likewise over the motions of many other organs in particular. All the other nerves, whether arising from the medulla oblongata or medulla spinalis, are summoned to their motion by the cerebrum, as may abundantly appear from a practical and theoretical enquiry

into the nerves. Nowhere does the par vagum receive sensations and transmit them to the cerebrum. And if it does act on any membrane that is sentient, or on any muscle that acts from the will, nevertheless in the same membrane or muscle we always see nerves proceeding from another origin, which is of such a nature as to shew that it is they which perform this office; thus the par vagum appears to arise from the cerebellum just as much as the intercostal nerve. I am not now speaking of the lesser trunk of the par vagum, nor of the spinal accessory nerve, which is determined to the place where the voluntary action affords an origin for the spontaneous action of this nerve; both being therefore incorporated into one trunk, that they may always coincide and agree. Both these accessory nerves, the one arising from the medulla oblongata, the other from the medulla spinalis, pass under the governance of the cerebrum; as shewn by the action of the larynx, pharynx, and tongue. Moreover, from the very origin of the par vagum under the fourth ventricle, it may be inferred, that it springs out of the medulla cerebelli, where it passes into its processes; but still it is not so evident even from this, as from the functions the nerve performs at its extremities; for instance, from the fact, that immediately after its origin, it suffers itself to be acted on by the cerebellum, its fibres to be acted upon by the alternate distractions and constrictions of the fourth ventricle, and the fascia itself to be acted upon by the great eminence itself with its transverse hoopwork, where it emerges between it and the olivary processes.

491. For this use the nerve prepares itself from its earliest stages; for it brings out with it as many bundles as there are origins of such motions in the body.—It is worthy of observation, that this nerve carries out as many fascicles from its natal soil as there are retiform plexuses, or what amounts to the same thing, as there are common origins of natural motion in the body. Most anatomists have enumerated eight fascicles, but Ridley has seen twelve. (*Anatomy of the Brain*, chap. xvi.) So also there are eight great plexuses, and four small ones; shewing that each fascicle appears to be meant for its own plexus. Thus there are two pneumonic plexuses, one large and one small, as mentioned by Winslow;<sup>x</sup> there are two cardiac plexuses, one large and one small; there is the sto-



machic plexus, which is rather a nerve ramifying toward the pylorus, or perhaps a coronary nerve; there are three mesenteric plexuses, one splenic, one hepatic, and two renal. If the smaller plexuses be not regarded distinctly in the fascicles, then there are only eight plexuses, because the four small plexuses coalesce with the larger; they are also frequently so dependent upon the larger, that their beginnings or fascicles are convoluted under the same tunic, just as is the case with the small cardiac plexus, the pneumonic, and the two renal plexuses. This appears to be the reason why each fascicle goes immediately under its own envelope, and why the different fascicles, before they coalesce, are frequently sent out through a separate foramen, which is therefore called the foramen lacerum.

492. But since it descends on both sides as a single trunk, it is necessary that everywhere, and particularly in the plexuses, it should be associated with the intercostal nerve, that it may be recruited, whenever occasion demands, with spirituous fluid.—For the intercostal nerve has not less than about sixty origins, and if one or more of these be intercepted, still the part of any viscus dependent thereon would be easily supplied by the other twigs of the nerve: but the case is different with the par vagum; for if any of its fascicles or principal branches be amputated or cut off, it no longer derives any spirit from its cerebellum or living fountain. For this reason it is adjoined in every part of the body to the great intercostal nerve, to live by its mediation, as experience teaches. Thus Willis says: “When I put a tight ligature upon both trunks of the par vagum in the neck of a dog, I immediately observed . . . a very considerable tremor of the heart, but this affection shortly ceasing, . . . the animal lived for several days, and died at last, gradually worn out, in consequence of prolonged fasting.” (*Cerebri Anatome*, cap. xxiv.) And Lancisi observes: “When the par vagum, . . . or any other of the nerves on one side, is tied, the motion of the heart, although disturbed, does not cease entirely” (n. 463, p. 435). The same results have been obtained in experiments made by other anatomists. The trunk of one side, indeed, comes in aid of the cardiac plexus when the trunk of the other side is cut, or rendered useless; but this, in a very reflex manner, as will appear in the sequel: hence the resuscitation of the plexus is owing

principally to the intercostal nerve, which perhaps so inserts its fibres into the branches of the plexus, that in penetrating through the muscles, it never travels alone. Thus these two common nerves are like a married pair; the intercostal doing the husband's office, and the par vagum, the wife's. And this is the reason why the par vagum proceeds at once to the beds of the other; for as soon as it passes out of the cranium, it enters the cervical ganglion of the intercostal by numerous branches. Therefore it appears, that the proper cardiac nerves, in their functions, and when acting on the muscular fibres, are not distinct, as their origins would make them, but intimately united, and that the fibre of the one is wedded to the fibre of the other, so that it cannot be affirmed, that either of them, to the exclusion of the other, presides over the motion of the heart.

493. But perhaps it might seem that were this the case, there would be no need of the par vagum, since the fibre of the intercostal nerve alone would be sufficient, because it can be in no danger of losing its fluid; yet if we consider the subject more deeply, it will be evident, that both the one and the other is requisite and necessary to subordinate and coördinate the natural motions of the body, called by some the involuntary motions; the one to descend by a single trunk, and the other to arise from numerous branches, and associate itself with the former. For in the body there are subaltern motions, one not coinciding with another; there is the motion of the lungs, of the trachea, of the œsophagus, also of the stomach and intestines; there is the motion of the liver, or of the gall-bladder, which also is excited to action by peculiar causes; there are the respective motions of the mesentery, kidneys, bladder, uterus, &c. In order for these motions to be concordant, they must depend entirely upon a nerve with one trunk; with a trunk that has its fascicles distinctly compacted and associated under one tunic. For in order to exist and subsist, they must be under the auspices of one universal motion, or under the animation of the brains. The trunk itself, together with all the fascicles it encloses, is in this universal motion; and manifestly so in its place of birth, since its fascia is applied to a lobe of the cerebellum, which is so full of ridges and furrows, that it is carried to and fro every time the cerebellum animates; for it comes out beside the olivary



processes, and that they have an alternate action of the kind, is plain enough from the transverse and perpendicular notch cut upon them. Then again, the originative fibres of this nerve are so distributed under the fourth ventricle, that at every expansion and constriction of the ventricle, (that is, of its inside and fundus,) all the fibres arising under it, are similarly moved. Add to this, that immediately under the threshold of the cranium, it applies itself to the jugular vein, that it may be kept in the same motion, and on the other hand, that it may also keep the vein in the same; for the blood is driven from the lateral sinuses into the jugular veins at the moments of the expansion of the cerebellum, on which these lateral sinuses lie, and to whose patronage they are confided. Moreover, from the moment of its descent, it runs between the jugular vein and carotid artery, and often communicates with them. It likewise sends out several branches into the upper cervical ganglion of the intercostal nerve on both sides; which ganglion is evidently kept in the stream of the universal motion, or of the animation of the brains; because the intercostal nerve comes all along from the spinal marrow, and indeed from its little hordiform ganglions, which are set at the internodes of the vertebræ thus moved, and are constructed of the medullary fibres, tunics, and even blood-vessels of the spinal marrow. To say nothing of the manner in which the par vagum descends through the thorax, and perforates the diaphragm, where it is kept in the stream of the pulmonary motion, which is synchronous with the animatory motion of the brains. These considerations shew, that the trunk of the par vagum at its origin proceeds under the auspices of the universal motion; and inasmuch as this motion is the chief of all, and that under which all other motions subsist, it follows that some nerve is required to compact into a single trunk the fascicles devoted to the subaltern motions, and at every alternation, to reduce and combine them into one universal motion, with a view to provide against perpetual discord; for wherever the subordinate and subaltern is, the universal must also be.

Thus in order to prevent such a nerve from being anywhere deprived of its fluid in a degree proportioned to the impetuosities of the motions it excites, as those of the heart, ventricles, intestines and other organs, it must everywhere be so associated

to the intercostal nerve as to be endowed with life and spirit under the auspices of the latter; for were it deprived of this conjugal fellowship, one branch or fascicle of the par vagum might demand from its parent cerebellum more fluid than the other, and the cerebellum might, for the sake of preserving the general equilibrium, proffer it more; which nevertheless it could not do without detriment to itself as the principal viscus, inasmuch as an equable state of it is required, because its action is most constant. The case would be otherwise supposing the deficiency of nervous fluid to be everywhere supplied by the intercostal nerve in the body, because arising as this nerve does from so many different sources, it cannot elicit more from one sinus of the cerebellum than from another.

494. Now that this is the principal reason why the par vagum is sent down by a single trunk into the provinces of the body, may be evidenced by this consideration, that previous to its coming from the cranium, it summons another, namely, the spinal accessory nerve, as also another little trunk, (called the superior and smaller trunk,) and envelopes it with its own tunic; for each of these is a voluntary nerve, as may be proved in a variety of ways; the larger or inferior trunk alone being dedicated to spontaneous motion; which is abundantly evident from a contemplation of all these nerves in the extremes, and from the separation of the spinal accessory nerve from the larger or inferior trunk the moment it comes out of the skull. The reason why these voluntary nerves are associated with this trunk, will be easily seen upon examining into the origins of the natural motions. For the origins of these motions are either corporeal, as in the case of the intestines and stomach, and consist of twitchings, prickings, or other excitations of the nervous or muscular tissues; these viscera, even after death, and even when removed from their native abodes, being capable of similar motions and verminations: or their origins are voluntary, as are those of the œsophagus and trachea, acting voluntarily in unison with the pharynx, larynx, fauces and tongue, the motions once begun by which organs are continued in a spontaneous fluxion. To the end, then, that what is thus spontaneous may coincide with what is voluntary, or that the effect may correspond with its causes, the spinal accessory nerve and little superior trunk are added to



the par vagum under one and the same tunic, so that both may be fitly related by the fibres to the branches, and by the branches to the trunk, and by the trunk to the brains, and that these respectively distinct parts may act under the auspices of one universal motion; that each, for instance, may have its distinct life, and from this distinct life perform its distinct functions; for the spirituous fluid, which is the one only vital fluid, is expelled into all the fibres when the brains animate; consequently, unless all the parts were kept under the influence of this animatory motion, the animal economy, with each particular part of it, would collapse and die.

495. Perhaps the reader will pardon me for dwelling still a little longer on the exposition of the par vagum; since the motion of the heart depends upon this nerve, in concert with the intercostal. If we trace these nerves from the beginning to the extremities, and inquire into the specific actions of each (n. 473), it will be very evident that the *smaller trunk* of the par vagum is designed to forward the masticated food into the œsophagus, or is the internal deglutitory nerve; and at the same time enjoys some general sense of taste. That the *spinal accessory nerve* is designed to forward the food swallowed, from the pharynx to the upper orifice of the stomach; or is the external deglutitory, because it superadds the force of the external muscles. That the *branch of the fifth pair* in the tongue is properly masticatory, and at the same time subtly gustatory; so that the functions of the three nerves now mentioned, succeed each other in a given order. That the *recurrent nerve* is the general regulator of sound, or of the air passing out of the lungs by the trachea and larynx, when the functions of speaking, singing, and in a certain respect those of masticating and swallowing, are performed. That the *nerve of the ninth pair* is properly locutory, auxiliary to which is the *branch of the portio dura of the seventh pair, or auditory nerve*. Farther, that the *first cervical pair* forwards the food through the gullet, but in so doing only arranges the external forces. That the *second cervical pair* adapts the state of the larynx and windpipe to the motion of speaking. Nor can the first or second discharge its function, unless the lungs and belly, or entire subjacent region, conspire to favor it, which is the office of the *third pair of cervical nerves*. These act

upon the pectoral or anterior part of the thorax, but the *fourth pair of cervical nerves*, with the same end in view, act upon the dorsal or posterior part, &c. (n. 368). All these particulars might be proved in a variety of ways, were we at liberty to transgress the limits of the present Part. With respect to the *recurrent nerve*, we have said thus much in order to shew how all those fascicles and nerves that contribute to the production of the whole natural action, ought to be contained under the integument of the par vagum; to the end that the subordinate natural motions, may all be comprised as it were under one universal motion.

496. The recurrent nerve is termed the general regulator of sound, or of the air passing out of the lungs by the trachea, larynx, and glottis, whenever the function of speaking is performed, and in a certain respect, that of masticating and swallowing. For the par vagum, in commencing its egress, sends out a little branch to the superior cervical ganglion of the intercostal nerve, and at the same time inflects another towards the larynx and pharynx: in the larynx this other is inserted into the recurrent nerve, which arises in the right side from a certain ganglion, called the dorsal ganglion of the par vagum, and after being sent down the whole length of the trachea, along with the superior nerve we have just mentioned, the two coalesce behind the cornua of the thyroid gland. The same thing generally takes place on the left side. The muscles which these two recurrent nerves supply, are the hyo-thyroid in the larynx; the stylo-coraco-hyoid, the genio-hyoid, and the mylo-hyoid in the os hyoides; the cephalopharyngeus, sphenopharyngeus, stylopharyngeus, and sphincter gulæ in the pharynx; from which it is evident that the motion of the tongue, as received from the recurrent nerve, (and which takes place when speaking, masticating the food to be swallowed, and forwarding it to its ultimate destination,) is through the medium of the par vagum spontaneously continued to the parts below. And because this nerve is expended upon the pharynx, it must be reflected from below, and recurrent, but coalesce with the superior nerve in the larynx. When a single organ, as the tongue for instance, concurs to perform several simultaneous and successive functions, both generally, particularly, and contingently, there is



need of some common regulator to govern both the larynx and pharynx, and which when once acted upon according to the fluxion of its fibres, may itself act without any previous exercise of the will, or may afterward promote the performance of the voluntary act spontaneously. For the actions of mastication, deglutition, and forwarding the food, are all in one line of progression, since one may come after the other, one may exist and be performed with or without the other ; and for each particular operation therefore particular nerves are required, and also a wonderful connection or communication between them. But the actions of speaking and modulating in the same organ modifying itself and articulating, concur with the actions above mentioned, which therefore require their own nerve, their own nervous fascicles of the same, and their own particular plexus. Hence, as all these things concur in the tongue, there is need of some general regulator to govern the larynx and pharynx, lest the œsophagus should exercise the act of swallowing at the same moment in which the trachea is respiring ; otherwise the simultaneous and distinct action of the nerves of the fifth, eighth, and ninth pairs upon the muscles of the tongue, would be impeded, as also the distinct action of the muscles of the os hyoides, larynx and pharynx. Hence when the œsophagus acts, the stomachic plexus and par vagum on both sides act also upon the recurrent nerve ; and this upon the superior branch with which it is connected by anastomoses in the scutiform cartilage and thyroid gland ; and thus the larynx is closed, and the lungs cease to respire. But when the larynx acts with the lungs, the par vagum comes into play, and likewise the highest cervical ganglion of the intercostal nerve ; the motion of both of which is the one universal motion, or the motion of the brains synchronous with that of the lungs, by means of which the pharynx and œsophagus are alternately closed. And for this end, the œsophagus is tied up to the larynx and trachea, and at the same time passes through the diaphragm in company with the par vagum, lest one should act simultaneously with the other, the tongue acting in conjunction with it by means of a communication between the nerves. The case would be otherwise were there one organ for mastication, and another different organ for speech. In the meantime, the process of mastication can be performed

separately from that of deglutition, and simultaneously with that of respiration ; a passage for the air being provided through the nostrils. The case is not the same, however, in regard to deglutition. From what has been stated we may infer, that the general motion of the stomach derives its origin in some measure from voluntary action, as of the cheek, tongue, throat, pharynx; of the food thrown into the œsophagus through the medium of the smaller portion of the par vagum and the spinal accessory nerve; and then afterwards becomes spontaneous through the medium of the large portion of the same par vagum. There is again another origin of the peristaltic motion of the stomach, which has also its subordinate special and particular motions; for the par vagum is continued by its plexuses into the intestines, as the duodenum, jejunum, and ilium, and in some measure into the cœcum, colon and rectum; but from the colon a mixed voluntary motion begins, for the sake of carrying the excretions forwards. The par vagum is continued also into the mesentery, liver, and gall-bladder, and in some measure into the kidneys, over all which the motion of the stomach presides.

497. Among these several motions, which are all under the regulation of the par vagum, and subjected to the one most universal motion, we may enumerate that of the heart, which may be called a universal inferior motion, for it has under it the whole arterial and venous system of the body. But in order that in these continuous vessels, the fluent wave, agitated by different motions, may perform its perpetual circle amid such an immense variety of operations, it is most wisely provided, that each vessel, as well as the heart itself, and the larger arteries and veins, nay, the very least, shall have offsets of the par vagum and intercostal nerve sent into it, so that these offsets are the chief agents in the viscera, and regard everything only as the progeny of their own fibre. Wherefore, when the nerves thus produce their motions, they govern each vessel conformably to the motion, and while they reduce it to the motion of the heart, they reduce it at last to the universal motion of the brains. Otherwise the wave would foam at the mouth of every vessel, charybdic whirlpools would arise all over, and all communications would be intercepted; under which circumstances the orders of all things would be deranged, their connections would



fall asunder, and what was before agreement, would become discord, surd, irrational, and non-existent; and this, in man, to a greater degree than in other animals, agitated as he perpetually is by so many unregulated motions. But let us now pass to the remaining clauses of the induction.

498. *And into the cause of the action of the great cardiac plexus, and the nerves that depend upon it, particularly.* On this subject see the works on anatomy, *passim*. But I cannot give a better description than that elaborate one of Vieussens, in his *Neurographia Universalis*, tab. xxiii. This plate exhibits the true cardiac nerves, with the greater and lesser plexuses, (though these not so clearly as we could wish,) and also the intercostal nerve, and the par vagum; and I have transferred it to my work as a beautiful exposition of our present doctrine. But the plates of other authors also, and particularly of Lancisi, *De Motu Cordis*, &c., tab. i. iv. vii., deserve to be carefully consulted, as they shew the nerves of the posterior part of the heart, and particularly those that invest the coronary vessels. With the plate of Vieussens we ought to become familiar, in order that the several clauses that follow on the motion of the heart, may be clearly understood. For this reason, I shall give the description of these nerves presented in the plate, word for word from Vieussens.

499. In this plate, then, K indicates the anterior region of the heart, denuded of the pericardium and of the sanguiferous ducts. L the right auricle. M the left auricle. N the descending cava cut off near the right auricle. O the ascending cava cut off a little above the diaphragm. P the pulmonary artery cut off near its origin. Q Q the trunk of the aorta divided into two parts, which are represented a little removed from each other, namely, where the superior cardiac plexus is seen interposed between the aorta and the trachea. R the right branch of the ascending trunk of the aorta. X the left branch of the same, which immediately divides into two smaller branches, the interior and lesser of which, Y, is the left carotid artery; the exterior ends in the left vertebral artery Z, and in the left axillary artery. † the descending trunk of the aorta cut off. T the origin of the right vertebral artery cut off. V the right ax-

illary artery cut. E, H, I, 16, 16, the trunk of the eighth pair of nerves, with its ganglioform plexuses on the left side. E, H, I, the same with the same on the right side. *a*, 24,  $\Delta$ ,  $\nabla$ , 37, &c., the intercostal nerve with its ganglioform plexuses on the left side. *a*, *a*, 24,  $\nabla$ , 37, the same with the same on the right side.  $\Delta$ , 30, a fibre arising from the superior cervical ganglioform plexus of the left intercostal nerve, which communicates by two twigs, 29, 29, with the left nerve of the eighth pair, and runs down to the anterior portion of the pericardium, and is distributed through it.  $\nabla$  the inferior cervical ganglioform plexus of the right intercostal nerve. 34, a little branch arising from this plexus, which runs down and perforates the pericardium; and then, after having received a little nerve proceeding from the superior cardiac plexus, sends a fibril, 35, to the coats of the aorta, and passing over the trunk of the pulmonary artery, splits into the fibrils 36, 36, 36, &c., that supply the front of the heart. 5, a branch from the right trunk of the eighth pair, that sends a fibre, 6, to the coats of the aorta. 5, 8, a fibre of the same branch, terminating in the superior cardiac plexus. 8, 9, 10, the trunk of branch 5, of which 10 is sent to the right portion of the pericardium occupying the posterior region of the heart. The offset 9, 11, 12, 12, runs like a girdle round the descending vena cava, where it opens into the upper part of the right auricle, and terminates on the cava after sending the fibrils 12, 12, 12, to the right auricle. 14, a twig from the right nerve of the eighth pair distributed through the right auricle. 39, 39, two small branches coming from the lowest part of the thoracic ganglioform plexus of the left intercostal nerve, of which the upper gives off three fibrils, whereof the upper 40, 40, here cut off, are distributed over the œsophagus and trachea; but the third, 42, unites with the left nerve of the eighth pair. The branches 39, 39, are at last deflected toward the middle region of the breast, and when they come to the back of the aorta, divide into several intercommunicating twigs, and together with fibres from the eighth pair, with which they interweave, form the great nervous plexus 43. *y*, a branch of the left nerve of the eighth pair, which besides producing the left recurrent nerve, sends a fibre, Z, to the superior cardiac plexus, and a fibre, 2, to the heart and left auricle. 43, the superior cardiac plexus, which



is much larger than the inferior. 47, 47, twigs proceeding from the superior cardiac plexus, and supplied to the coats of the aorta. 49, two twigs proceeding also from the lower part of the superior cardiac plexus, and coalescing, and which giving a fibril, 50, to the coats of the aorta, produce the inferior cardiac plexus, 51, and at length by their extremities, 52, surround the pulmonary artery in the manner of a ring. \* a little nerve arising from the right side of the superior cardiac plexus, which coalesces with a little branch, 34, and with it supplies the front of the heart. 45, 45, 45, fibrils from the same cardiac plexus, which like the fibrils, 44, 44, are seen cut off, and are spent on the pericardium. 46, a fibre from the left side of the superior cardiac plexus, which coalesces with fibre 2 of branch *y*. 53, a little branch from the superior cardiac plexus, which is distributed over the left auricle of the heart, and joins the twig 4 of fibre 2. 4 a twig of fibre 2, distributed over the left auricle. 3 a twig of fibre 2, distributed over the front of the heart, about its left side. 44, 44, 44, 44, fibrils from both sides of the superior cardiac plexus, which are distributed through the internal part of the lobes of the lungs, and the glands set in their upper part behind the trachea. 13, 13, 13, 13, branches of the eighth pair, whose offsets, here cut off, form by their interlacement the pneumonic plexuses. 15, 15, 15, twigs of the eighth pair of the left side, which are spent partly on the coats of the œsophagus, and partly on the heart.

500. But it is to be observed, that only the larger cardiac nerves are represented in this plate, and that there are several not there given, which enter the parenchyma of the heart; as those, for instance, that enter the back of the organ from the upper ganglion of the left intercostal nerve, and descending to the surface of the heart, invest the coronary arteries especially. And besides all those arising from the intercostal and par vagum, the phrenic nerve also puts in some offsets, as may be seen in Lancisi, (*Op. Cit.*, tab. vii., ed. Rome, 1745,) who furthermore remarks on the subject, that “the phrenic [nerve] . . . after penetrating the thorax, closely embraces part of the superior vena cava, and externally the pericardium itself, the membrane of which it supplies with certain nervous fibres, and from this membrane creeps through the annexed trunk of the

superior cava, not only to the right auricle and ventricle, but also to the plexus above alluded to" (n. 463, p. 434). This illustrious author describes also another plexus different from that mentioned by Vieussens. "A large plexus," says he, "... lies posteriorly in the base of the heart, between the pulmonary artery and the aorta, just in fact where the ductus arteriosus passes between those two great vessels. This plexus merits the most particular attention. For a multitude of nerves from each of the five pairs concurs to produce it, and it again gives off innumerable nervous filaments to the inner substance of the heart." (*Ibid.*, n. 463, p. 434.) Now the great plexus presented in the plate of Vieussens, lies between the aorta and trachea, and the lesser plexus between the pulmonary artery and the left auricle. But let us keep to the nerves figured by Vieussens, lest by going beyond them we obscure what is already clear. With respect to these we are to notice, 1. That the nerves of the right auricle arise principally from the par vagum of the right side, but not likewise from the intercostal nerve, nor immediately from the great cardiac plexus. 2. That the nerves of the left auricle also arise from the par vagum, but of the left side. 3. That the posterior part of the heart appears to be governed by the left intercostal nerve, according to Lancisi, *Op. Cit.*, tab. vii. [?] 4. That almost all the cardiac nerves form zones round the great orifices of the heart, as at the entrance from the superior cava into the right auricle 12, 12, 12, and from the right auricle into the right ventricle 36, 36, 36, 36: from the pulmonary vein into the left auricle 3, 4; round the pulmonary artery 52; as also between the aorta and the heart, as shewn again by Lancisi, *Op. Cit.*, tab. iv. vii. 5. Moreover, that branches and twigs run down from these zones, on the surface of the heart, and as they run, split into finer twigs; a fact that should be carefully noted. 6. That there also are nerves, which do not descend from any of the zones, but immediately from the trunk, or from a branch of the par vagum; as 14, 15, 15, 15, &c.

501. It was shewn above (n. 426), that the nerves of the coronary vessels are intromitted to the surface of the heart from a different origin to the proper nerves of the muscular substance of the heart; in order that the coronary vessels may be able to perform their diastole when the heart performs its systole, and



*vice versâ*; for did both sets of nerves depend upon the same origin of motion, then at the same moment they would straiten the fibres and the tunics of the vessels themselves, and compel them to perform the same reciprocations. This cannot be better seen than from Lancisi, (*Op. Cit.*, tab. i. iv. vii.,) who traced the cardiac nerves with an especial view to ascertain what nerves are supplied to the coronary vessels, and the course of these he has most accurately investigated. It is worthy of remark, 1. That the nerves which command the coronary arteries so called, descend principally from the uppermost ganglion of the left intercostal nerve, along the aorta, and even along the pulmonary artery. "On the left side," says Lancisi, "from the second pair of nerves, that reach to the heart, a large branch issues from the superior ganglion, and descending along the carotid artery, as soon as it reaches the aorta, enters its external coat, and penetrating the pericardium (besides the offset that it sends over the external surface of the heart, to accompany the coronary artery on the back part of the same) is immediately inflected when it comes in contact with the pulmonary artery, and like a new stay binds down the trunk of the aorta, where it is attached internally to the pericardium; and then becomes recurrent to the trachea and œsophagus (n. 463, p. 434, 435). The nerves that . . . are distributed over the posterior surface [of the heart], run at the side of the aorta. . . . They entwine the trunks and branches of the coronary arteries, as ivy wreathes its clasps around the trunks of trees: and indeed they strengthen and invest the arteries as it were with little nervous sheaths. . . . And here we have observed, not without admiration, that the little nerves that accompany and invest the small arteries, are inserted and penetrate chiefly at the parts where the latter are strengthened with delicate sphincters." (*Ibid.*, p. 435, 436.) Shewing that all the nervous twigs sent to these arteries, arise immediately from the intercostal nerve; while the others, that enter into the muscular substance, proceed from another origin, and first indeed form zones or belts, as it were circular stays, around the orifices, and from which twigs proceed. 2. But those nerves that run to the proper arteries and veins of the auricles, Lancisi has not delineated, but Vieussens in his plate has represented two, 14 and 53, which do not proceed from the zones, and

which, we may conjecture, pass into the above vessels ; and so enable them to perform their diastole when the auricle performs its systole, and *vice versâ*. 3. The coronary veins so called are governed by the nerves that are collected in the substance of the heart, and afterwards run to the veins, accompanying their branches ; as appears from this observation of Lancisi : “ A far larger quantity of nerves,” says he, “ is supplied to the coronary arteries, than to the accompanying veins. . . . In the veins they appear to creep along, and to become as it were reflected from the apex to the base, (while in the arteries, as he states, they are “ adherent from the base to the apex.”) . . . With respect to the nerves, we could clearly see that they everywhere accompanied the blood-vessels, and always became greater, and were augmented, within the heart” (n. 463, p. 435, 436). A sure sign this, that when the heart swells up, the nerves are drawn upon by these their boundaries fixed in the substance of the heart, and thus that the vessels are contracted, and urged to expel their blood. Likewise also the coronary arteries, by their fixed boundaries between the aorta and pulmonary artery, and the ventricles ; for the nervous stays designed for the coronary arteries, and for the coronary veins, (arteries and veins that discharge themselves into the aorta and into the right auricle,) cannot have the same localities, because the auricle associates with the ventricles in one way, and the aorta and pulmonary artery in another ; the former superinduces itself upon the ventricle in the manner of a fringe or crest, while the latter is continuous with the ventricles ; so that the origin of the nerves for the so-called veins must be from the muscular substance of the heart, and the origin for the so-called arteries must be in the confine between the aorta or pulmonary artery and the ventricles, in order that the systole of all these may coincide with the diastole of the ventricles, and *vice versâ* (n. 423, *seqq.*). But all the nerves thus brought in, depend on the general motion of the heart ; and the more manifestly, as it is plain that these vessels are continuous with the tendons of the heart.

502. *And moreover into the cause of the action of the muscles ; for the heart in all respects is a muscle.* Everything in the animal machine that lives by acting, is furnished with a motive fibre, which is what acts, and its fluid is what lives ; and as in the



softer parts there is nothing but lives, and nothing but acts, it follows, that a motive fibre of some kind is the main constituent of the body. And if anything seems to have ceased to live, as the indurated tendinous or ossified parts of a muscle, still experience shews that in its first infancy it consisted of motive fibres. Nevertheless, the parts that have thus become indurated, have their own cause; for they perform a general cause in the same place, where originally, and when they were in distinct fibres, they performed every particular cause. Since then the motive fibre rules everywhere in the machine that lives by acting, so the Doctrine of the Motive Fibre holds a principal place in the science of the animal economy, and requires a lengthy Part to be devoted to it. But as I do not here profess to treat of the subject, I will merely state principles almost unaccompanied by experience, although really deduced from it. Yet since there is more weight in one fact than a thousand reasonings, I will let fact plead its own cause in the Part above alluded to.

503. This, the truly physical doctrine of the body, is to be derived from the following maxims:—*First*. Nothing lives in the body but the spirituous fluid: other fluids, which are to be called derivative, live only so far as they rightly and determinately contain the spirituous fluid. On this subject we have often spoken already (n. 37, 97).

*Secondly*. In order that this fluid may live by acting, it is necessary that it be in a fibre, by which it may be distinctly determined: therefore there is nothing that, as an efficient cause, truly produces action, except the fibre with this its fluid. Other vessels, with their enclosed fluid, which may be called derived fibres, act only so far as they rightly and determinately contain this fibre. On this subject also we have often spoken above (n. 133, 136, 152).

*Thirdly*. There are as many distinct degrees of motive fibres as there are of fluids in the vessels, one of which fibres is subordinate to another, just as the causate is subordinate to its cause. Therefore the *first*, or primitive motive fibre, is the very fibre that in the brain is called the medullary fibre, but in the body, the nervous fibre. The *second*, which is derived from the first, is the vessel of the purer or white blood, or the fibre that is constituted of those former vessels, and is called in general

terms, the white motive fibre. The *third* motive fibre, which is derived and compounded from the first and second together, is the vessel of the red blood, or the fibre constituted of those former vessels rightly determined. As this last is conspicuous to the eye, it is properly called the motive fibre; or even the muscular and fleshy fibre. The *fourth* motive fibre is the muscle itself, which is composed of, and duly evolved from, its own motive fibres. There are then four degrees of motive fibres, the first of which we may term simple, and the last highly compound: and all subordinated to each other in the manner of first, mediate, and ultimate efficient causes. But of this, too, we have frequently spoken above (n. 273—279, &c.). And experience herself is fruitful and liberal, and so to speak, prodigal, in confirming these positions.

*Fourthly.* The simple motive fibres act in the same manner as the compound motive fibres; or the nervous fibres in the same manner as the blood-vessels; with this difference, that the former act more perfectly; on this subject also we have already spoken (n. 472).

*Fifthly.* The simple fibres, by means of their fluid, can act upon the compound fibres and their fluid; and *vice versâ*, the fluid of the compound fibre can act upon the simple fibre and its fluid: thus there is action and reaction, without which no reciprocal motion, such as we find in the muscles, can exist and subsist. Hence the nervous fibre, by means of its fluid, can act upon the vessel and its blood, and the vessel, by means of its blood, can act upon the nervous fibre and its fluid; giving birth to action and reaction, without which the muscle cannot reciprocate its motions. Hence the simple fibre can act upon the vessel of the purer blood, and *vice versâ*; as in minute animalcula or insects, and in the little membranes or other parts of the larger animals, where all things are white, and yet most active. And hence the simple fibre, by means of the vessel of the purer blood, can act upon the vessel of the red blood, and *vice versâ*, as appears in all the fleshy muscles; which, when their fibres are cut, compressed, emaciated, or rendered useless, immediately cease to act; or when the blood-vessels, as the arteries, are divided, compressed, stopped up, or otherwise rendered useless, again immediately cease to act. Consequently



the simple fibre, by means of the vessels of the purer and red blood, in a chain of order, can act upon the entire muscle ; and *vice versâ*, the entire muscle, by means of the same vessels, can act upon the simple fibre ; as one antagonist muscle upon another, which when it undergoes collapse, the reciprocation of the motion immediately ceases.

*Sixthly.* The least arteries are more immediately under the government of the nervous fibres, and hence of the brains, than the large arteries (n. 234). For the least vessels, like motive fibres, surround even the large arteries and veins in the manner of rings, whence the nervous fibre acts upon the least vessels first, or through them upon the blood of the whole large vessel.

504. Therefore the real efficient cause of the motion of the muscles, is the fluid in the fibres, and the fluid in the vessels ; or what amounts to the same thing, it is the action or force of the spirituous fluid by the fibres, and the reaction of the blood by its vessels. If then there be the same relation of the fibres to their fluid as of the arteries to theirs (n. 472), it follows that the similarity of relation will extend to the following particulars. 1. That the spirituous fluid runs through the fibre just as the blood through its vessel, but much more perfectly, swiftly, &c., since it is in an eminent or superior degree. The blood runs through its vessel by undulation, the spirituous fluid, through its fibre, by modification ; therefore similarly ; because undulation corresponds to modification in its degree (n. 166). 2. The nervous fibre, permeated by its fluid, in the extremes, where it has gained its liberty, because it is no longer compacted into fascicles, or surrounded by a series of tunics, expands both lengthwise and breadthwise, just as the artery (228, 229, 230), 3. Therefore when the fluid acts in its fibre, and expands it both ways, and at the same time the vessel, round which the fibre winds in continual circles, (there being therefore room for the blood to flow in) ; and *vice versâ*, when the fibre constricts, it then compresses itself around its vessel, and expels the blood. That the blood thus expelled continually repels and reacts, is a consequence of the equilibrium of general pressure acquired and preserved by the circulation (n. 178—182), and without which equilibrium, therefore, no muscular action would be pos-

sible. This then is the reason why the contracted muscle is pale, hard, constricted, and acts on its tendons according to the mechanical direction of its fibres, and by these tendons upon parts capable of being drawn, elevated, or moved. With these positions laid as a basis, let us see what is the cause of the action of the spirituous fluid, which enables it to produce this effect in its extreme fibres.

505. This cause, on the shewing of general experience itself, and also of all particular experience, is the brain ; for when the brain wills, the muscle at once rushes into action, nor can the muscle derive its action from any other source than that from which the fluid runs out from its principles or first starting-places along all its fibres. It will be seen when we come to the anatomy of the brain, that every fibre has its own *corculum* and *cerebellulum* prefixed to it, or its own spherule of cortical substance ; that this substance is divided into its cortical *thalami* and *congeries*, and these *congeries* are so combined and conglomerated, that each can be distinctly compressed and expanded, or animate in its own particular locality ; hence deep cavities are cut between the serpentine ridges in the brain : when therefore one or the other of such *congeries* animates, the spirituous fluid is determined into the dependent fibres as from little hearts ; those fibres in the extremes are expanded or constricted in length and breadth ; consequently the motive sanguineous fibre also, and through the medium of the sanguineous fibre, the whole muscle. For if the spirituous fluid be highly elastic, and if its fibre be highly correspondent to it, so that the two act as one and the same cause, just as we have above observed with respect to the arteries, it follows, that no impressed force perishes, but is the same at one extreme as at the other ; as we find to be the case in the atmospheres, the parts of which are highly elastic. The *tori* of the cortical substance are formed in diverse manners. In one place they are narrow, in another they dip deeply into the medulla, in another they keep near the surface ; as shewn by Ruysch, *Epist. Anat.* xii., tab. xiv., fig. 2, representing the cavities denuded by the removal of the *tori* of cortical substance. The same appears from the processes of *pia mater* that dip down into the furrows or folds, and as this author describes, creep about in a serpentine manner, and not



in a falciform manner as in the cerebellum. (*Epist. Anat.* vii.) That these tori are capable of being expanded and constricted, both particularly and generally, in their places or spaces, is evident from the thin, reticular, and expansile membrane that surrounds them, and from the circumscribed space in which they can intumesce; also from the continuation of the pia mater solely into processes of such a nature as do not hinder the elevation of the brain any more than does the falx of the hemispheres, but do prevent any divarication of the parts. Moreover, the little arteries that are put in, traverse the parts in a retiform manner, and then suffer themselves to be relaxed and constricted. And here and there there are largish vessels between the cortical and medullary substance, as shewn in one of Ridley's figures (*Anatomy of the Brain*, fig. 5); and also little sanguineous reservoirs in the medullary substance and centre, so that when the tori act one by one, they may have their own proper receptacles from which to derive their blood, and into which to remit it when they cannot send it into the common streams, or when any particular constriction does not for a long interval coincide with the general constriction. For the oily lymph which (according to the testimony of Ruysch and Pachioni, n. 150) fills the anfractuositities, and their apparent smoothness attested by Leeuwenhoek (Part II., n. 71), is a sign of their state of motion, as it is of that of all the joints of the body where any motion is found. That voluntary actions exist from similar constrictions and elevations of the tori, is proved by experience, as in apoplectic and epileptic persons, and in others who suffer under frequent convulsions of their members; for concretions of blood or serum, inflammations, indurations, hydatids, obstructions, and such like, when occurring in the brain, deprive it of its faculty of elevation, and cause an inaction or convulsion of the corresponding member. But when the cortical tori are cut as deeply in as the medullary substance, the animal is agitated with extraordinary spasms, as we learn from Ridley. (*Philosophical Transactions*, n. 287, an. 1703; and our Part II., n. 1). We now come to enquire what cortical tori correspond to the respective muscles in the body, and this we cannot ascertain except from experiments on living animals,

by puncture, section, and compression in a variety of subjects, and then observing the effects produced in the muscles of the body. We may however conjecture, that those are in the greatest activity, in which the largest rivulets of blood are found. Moreover the cortical torus does not act on one or the other particular fibre, but simultaneously upon the whole fascicle of fibres, as is evident from the anatomy of any particular torus; for in it the cortical substance is arranged in the form of clusters or acini, and between these there are interstices, because when any colored liquid is passed into the torus, the boundaries of these acini are defined, and the tori, if skilfully divided, exhibit arborescent ramifications not unlike those in the cerebellum; according to the experience of Malpighi (Part II., n. 79). The fibres of all these ramifications combine, and are then sent out by the same number of peduncles into the medullary substance, producing in this substance the appearance of strata and lamellæ of fibres. It is therefore from a compound action of the torus upon the fascicles that the effect ultimately produced upon the muscle results—an effect which arises from a multiplicity of forces, and which is accordant with the will of the determining soul. But in the Part on the Anatomy of the Brain, we shall further shew that the brain itself, by its power of animating particularly, does not act immediately upon the fibre of the muscle (except perhaps upon that of the foot and toes), but upon the fibre of the two medullæ, and thus mediately. The wonderful contrivance by which this is effected can be satisfactorily shewn only in the Part on these subjects. See n. 574. This then is one cause of the action of the muscles, or of the voluntary action—the cause *on the part of the brain*.

506. There is also a cause of the action of the muscles *on the part of the body*, namely, every cause that compels the nervous fibre to act, as the artery does when a pressure from without expels the enclosed blood through its extremities. To illustrate our meaning, let us continue the comparison. When anything compresses, pricks, elevates or stretches the artery, this is a cause for which the blood it contains runs out through its extremities; nay, even when anything intercepts the continuity of the artery, or intervenes to close it, as for instance,



externally any ligature, or internally any grumous substance and polypous concretion, the blood is nevertheless spontaneously expelled from the artery, inasmuch as the former is always in a state of general pressure (n. 178). The same holds good with regard to the nervous fibre; whatever compresses, pricks, elevates or stretches it, is a cause of its spirituous fluid rushing through its extremities, which it does even though the continuity of the fibre, or the current of its fluid, be intercepted. This is the case more especially when we consider this fluid to be in like manner placed in a state of general pressure by means of the animation of the brains and the circulation thence arising, and the fibre to have everywhere the form of a continued brain, just as the artery has everywhere the resemblance to a continued heart. All the fibres of the cerebellum, or all the nerves arising from its fibres, such as the intercostal, and the eighth nerve of the head, are so distributed to the viscera of the body, that while the cerebellum distends them by its spirituous fluid, and as it were maintains them in the equilibrium of general pressure, the causes arising on the part of the body excite the muscles depending upon these fibres and nerves into the motion which is called spontaneous, their natural motion being called involuntary; for the cerebellum, unlike the cerebrum, cannot animate particularly, since it has no cortical tori capable of being elevated; hence it cannot animate from a will distinctly determined, but has only a common or general action, and inspires all its fibres simultaneously.

507. Consequently there are causes of muscular motion on the part of the body, which causes are numerous, and indeed as many as the natural motions. This is evident from the phenomena of the body. For, 1, when the stomach is excised, and removed from its natural situation, it readily exhibits the creeping motions peculiar to it, for the folds and gyrations belonging to its cavity it frequently after death presents in a state of motion, just as if it were still alive; this would by no means be the case unless the cause of its action arose from the body, for it cannot arise from the cerebellum from which it is now separated. This motion may even be produced *ad libitum*, if the villous membrane be excited by warmth, by the point of a needle, or other stimulus, just as during life it may be excited

by stinging particles, acrid bitter substances, emetics and purgatives. 2. The gullet also when excited by a voluntary act of the pharynx, fauces or tongue, moves the cardiac orifice of the stomach together with its ingesta, this part of the stomach moves again the stomach in general (n. 496), and the stomach rolling all things in its spires, urges them through the pylorus into the intestines. 3. Through the excitations of these parts, the chyliferous veins at the side, and at the same time the ductus cholidochus, and often the gall-bladder, and other of the vessels of the abdominal kitchen connected with them, are by means of the nerves and plexuses put into a perfectly facile and superabundant degree of action. 4. And the phrenic nerve, (which when chafed is said to excite the muscle of its septum,) and which owes the cause of its action principally to the three cervical nerves, from which it depends, when acted upon by the elevation of the ribs, clavicle, and sternum, and also by the expansion of the lungs, and in like manner by the constriction of the thorax, causes the expanse of the diaphragm to adapt itself to the respiration of the lungs, and acts in consequence its own part in determining the pulmonary space.\* 5. In like manner the respiratory muscles of the lungs, or those which naturally constrict the thorax, such as the intercostal, and even the sternal and vertebral, the nerves of which arise from the dorsal region of the spinal marrow, are excited to act not only by the action of the marrow itself and its hordiform ganglia, but also by the friction of the nerves in the foramina of the vertebræ, to the bodies of which they are fitted inferiorly and superiorly, so that while two ribs inserted into the vertebræ are elevated, the superior vertebra draws its nerve outwards, and the inferior vertebra draws its nerve inwards, giving rise to a palpable friction and palpable effect, produced by the nerves upon the ordinary muscles which so often open the thorax. 6. The pulmonic plexuses themselves act in a similar manner, for every time the air ex-

\* Ipse nervus diaphragmaticus (qui dicitur etiam frictus musculum sui septi excitare), qui causam suæ actionis præcipue tribus nervis cervicalibus, a quibus pendet, aque costarum, claviculæ et sterni elevatione, tum etiam a pulmonum expansione, sic constricto thorace, acceptam debet, efficit actus, ut expansum diaphragmatis secundum pulmonum respirationem applicetur, et suam quoque causam in spatio pulmonario determinando agit.



pands and stretches the bronchia, the plexuses also with their continued twigs and offsets are raised and extended, producing an effect upon all the vessels dependent upon them. 7. The large arteries and veins of the body preserve the mode of action which is natural to them, even though the nerves supplying them be separated from them, as we learn from an experiment made by Vieussens (n. 122). So that it is only the sanguineous wave which by expanding its vessels excites the circular muscle of the tunic. Consequently here also is a cause of action which arises on the part of the body. 8. The same law holds with regard to the heart, whose vena cava and auricle, even after separation from the brains or removal from the thorax, commonly return very soon to their accustomed vibrations upon contact with any foreign body, whether they be softly stroked by a warm hand, or touched with a needle or the finger-nail, or be injected with warm water in lieu of the blood they have lost. For a compages of this kind, the fibres and vessels of which have not yet begun to grow torpid from the loss of their fluid, or to be insensible to the effect of touch, or to widen their mouths in consequence of their rupture, lives in its own proper causes as long as any fluid remains in its nervous fibre, and is enabled to flow into it in place of that which has been expelled from the nerve; hence when the vessel or fibre, which is the predominant part of the organization, is touched, the fluid belonging to it is excited, and when excited, receives its modifications as it was wont. 9. And a nerve often is recurrent, as the eighth nerve of the head, and having performed its office in one viscus, throws itself back into some other, as for instance, from the heart into the trachea, œsophagus, some vein or other organ, and this it does frequently in such a wonderful manner as to be enabled to proceed instantaneously from one motion into another, and from this again into a variety of others. This is a fact which we may learn from the neurology of every part of the body; such, for instance, is the nerve of which Lancisi speaks, and which “like a new stay binds down the trunk of the aorta, where it is attached internally to the pericardium, and then becomes recurrent to the trachea and œsophagus” (n. 463, p. 435). Now unless this nerve were acted upon by causes in the body, the cerebellum, which is constantly animating and acting, could not possibly

with such particular determinations descend into all the multitudinous motions in the body, and from its first principles dispose itself into conformity with the causes which meet it only in the body, and of which it is afterwards rendered conscious.

10. This is the reason why even if the par vagum be compressed in the neck, or its branch be anywhere cut off, or be rendered useless by its inclination to become tendinous, or by any other cause, nevertheless if it be associated with the intercostal nerve, it will, in its middle and extreme parts, continue the natural motion of the viscus. 11. The par vagum therefore, together with its intercostal nerve, is transmitted from the cerebellum into all those viscera of the body which are governed by natural instinct, in order that it may act everywhere from causes arising from the body, and likewise upon the extreme ramifications of its several offsets; the cerebellum also has no other superintendence over it, than such as is requisite for infusing into it its spirituous fluid at the periods of its animatory motion; on the cessation of which infusion the action of the nerve ceases, because the life of the nerve is its fluid, in the same manner as the life of the artery is its blood; the artery dying whenever the heart dies. 12. The extreme fineness of the fibres can be no obstacle to the progress of the fluid, for it will only correspond to the fineness and volume of the fluid itself. Because the fibre is made in such conformity to its fluid, that the fluid travels as freely as if it were not propelled through its medium;\* there being a perfectly reciprocal correspondence between the fibre and its fluid, just as there is between the blood and its artery (n. 134, 135): wherefore if the fluid of the fibre is enabled, at the mere will of the brain, to act upon the muscle proper to it, so is the fibre able to act upon its own fluid, and this fluid to act upon the muscle from a cause derived from a source different from that of the brain, which is done without any distinction between the two; for traction itself (whenever it is done by traction) never extends from the trunk into the branches, and thence into the offsets, unless there be a similar action upon the offset, and one that is in conformity with the fineness of the fibre; if it be extended

\* Nam ita est conformata fibra ad suum fluidum, ut sive ipsa contingatur, sive fluidum immediate propellatur, idem resultet effectus.



from the trunks, it is merely friction, not traction, which is continued into the extremities of the fibre. 13. At every infusion there is only an extremely small loss of the spirituous fluid, inasmuch as no more is expressed than can in the branches thus acted upon be exhaled from the beginning of the motion to its terminations, according to the quantity of the moving force; indeed in one respect it is no loss whatever, since the whole of this fluid passes into the blood-vessels and returns to its first sources (n. 151—155). 14. In the following remarks I purpose to designate the cause which proceeds from the brain as *internal*, because the brain acts immediately upon the fluid of the fibre, and the cause which proceeds from the body as *external*, because it exists in the body and acts extrinsically upon the fibre. In the doctrine of muscle, artery and fibre, the following rule is of the first and last importance, namely, that in every particular point of an artery there is a likeness of the heart, and in every particular point of a fibre there is a likeness of the brain, and this, in such wise, that there is no point in an artery and no point in a fibre, but propels its fluid, just as if the beginning were there, and the heart or brain most absolutely present. Wherefore when any point of a separated fibre is touched, compressed, or otherwise modified, a similar modification instantly flows along all the little succeeding branches to the extremities, with this only difference, that touch here modifies but a small number of branches; namely, those only which are below the point of contact; while the cerebrum or cerebellum modifies all universally, as the heart modifies all the arteries (n. 570).

508. The external acting causes, therefore, are all the various species of contact that at any time excite the fibre in a way conformable to its simple or compound structure. The entire nerve acts in one way, its fascicle in another, the fibre itself in another; and the acting causes must answer to the order and degree of the fibres. The causes are, 1. Any puncture or twitching arising from sharp corpuscles, large or small, as in the intestines and stomach, nay, in the œsophagus, fauces, tongue and gums. 2. Any irritation produced by heat or cold, in which case the sensible fibres immediately constrict or expand, corrugate or smooth themselves; as everywhere in any fibrated membrane. 3. Vibration produced by causes exciting a tremor,

as in the trachea. 4. Tension and relaxation, such as take place when the intestines excite the bile of the gall-bladder. 5. Reciprocal friction and traction of a nerve, or of its tunic, or fascicle, as of the dorsal nerves in the foramina of the vertebræ. 6. Elevation and depression, as in the phrenic nerve, when the brachial nerves, or the ribs, or the diaphragm itself, are acting, or the lungs act upon the diaphragm. And everywhere in those nerves that depend upon the cartilages or other tendinous extremities of the ribs, clavicle and sternum, by means of the muscles acted upon by the will. 7. The intumescence extending and expanding the whole nervous and fibrillary tissue of a cavity, as in the heart and lungs. According to Lancisi: "When . . . [the nerves of the heart] are in a normal state, the motions of the præcordia are just and natural; but when they are depraved, or any irregularity occurs in their situation, number, figure, and size, or in any the least conditions of fullness, or emptiness, the motions then very soon become preternatural" (n. 463, p. 432, 433). In another place he says, "Sometimes when [the vena cava is] only punctured with a needle or with the point of a lancet, the intermitted motion is again renewed: and when the experiment succeeds, the cava (moving like the intestines) makes reciprocal peristaltic constrictions and vibrations toward the heart. . . . But what we have stated of the vena cava, during vivisections, ceasing from all motion, and recovering its beats when pricked with a needle, or stimulated by the application of a warm body, takes place also equally in every part of the heart, in the auricles as well as ventricles; a single prick, or the fresh contact of a warm body, being sufficient to cause irregular palpitations and fluctuations there also; provided always that the heart has not grown cold and stiff" (n. 465, p. 444). But more on this subject presently. 8. When either whole nerves or their branches are wounded, cut, injured, contused, or compressed, a manifest effect is produced on the muscles dependent upon them, as in spasms, convulsions, tetanus, apoplexy, epilepsy, &c.

The same observation holds with regard to all other parts of the body, and were I upon these principles to trace their myology, and at the same time the fluxion of the nerves into the muscles, I think I should be able, and much to my gratifi-



cation, (for what is more agreeable than the society of the Muses when they prosper our endeavors,) clearly to elucidate the forms of the respective actions of the body as determined by the influx of the nerves (n. 473).

509. Let the causes be given then, and we may readily conclude what are the effects produced in the muscles, what is the extension of their motion, what its duration, what its degree, what its celerity, what its determination from one point to another; for these particulars flow all as determinate consequents according to the acting causes. If they flow from an internal cause, or from the brain, then in this case, 1. Such as is the extent of the portion of cortical substance that animates particularly, such is the extent of the action resulting upon the nerves and voluntary muscles dependent upon them. Whence the disposition of the cortical tori, and the connection of the fascicles proceeding from them, exhibit the most ingenious arrangement. It is for this reason, moreover, that motion can be performed more quickly or slowly, and more strongly or feebly, or within a more extended or more confined space, according to the will of the determining power. 2. If they flow from an external cause or from the body, then in proportion as the nervous tissue is extended, vibrated, irritated, or affected in any other manner suitable to it, in the same proportion are the quantity and quality of the action which follows. 3. All other phenomena produced by external causes are regulated according to the disposition, determination and condition of the fibres; as, for instance, according to those of the nervous fibres, those also of the white motive fibres, and those of the sanguineous or fleshy motive fibres; for thus it is that the muscle, which is a compound of its own fibres, is excited, disposed, and determined to action. The phenomena are regulated also according to the situation and form of the motive fibres in relation to their tendons or extremities, and of these to the cartilages, bones or moveable points, the action of which is intended as the last determined action; they are regulated also according to the dependence of one muscle upon another. All of which being most wonderful determinations of nature acting, and these determinations being also mechanical, (for fibres of every order represent forces and powers, as in machines,) cannot be explained

in a few words, because there is nowhere throughout the body a single nervous fibre, a single motive fibre or muscle, which acts, flows, and is determined in a manner similar to another. Hence even to assign the general laws of motion is a task of immense labor; to point out, therefore, its various particular laws must be to dissert separately upon all the acting points in the body, not only in the human, but in that of every individual animal; consequently it would be to assign as many ratios as are to be found in the whole compass of arithmetic, geometry, mechanics, physics, and the algebraical calculus; and yet notwithstanding all this, there is not a single law which may not be found when the causes and effects are given and their intermediates duly investigated.

On the subject of the causes of muscular motion, that learned and experienced anatomist Winslow has the following observations: "The particular mechanism and immediate cause of muscular action has much puzzled the wits of numerous physiologists. The extreme delicacy of the texture of a moving fibre, and a great number of phenomena, some of them very obvious, which have not been attended to, have hitherto prevented the discovery of the mystery. Several hypotheses have been formed respecting the structure of this fibre, which . . . has been supposed spongy, vascular, vesicular, contorted, elastic, &c., and various ideas have prevailed with respect to the concurrence of different fluids with the supposed structure of the fibre. And systems have even been founded wholly on the spring or elasticity of the solid or firm parts of which a muscle is composed. But on considering attentively the phenomena already mentioned, . . . all these different systems fall to the ground. For hitherto no instance can be found, either in nature or art, of any explosion, fermentation, ebullition, injection, inflation, imbibition, vibration, elasticity, &c., by which we can regulate and determine to a given degree the space, velocity, and duration of any artificial motion, or by which we can begin and put an end to such motions in an instant of time at our pleasure. It is therefore to no purpose to amuse ourselves with what has been said upon this subject: another method must be followed, which consists in collecting and examining all the facts and phenomena that can fall under our observation. Till some



such lucky discovery is made, what can hitherto with the greatest certainty be gathered from the structure, conformation and action of the muscles, is, that their strength depends on the number of their fleshy fibres, and the quantity and extent of their motion, on the length of these fibres. For wherever strength is more necessary than extent or range of motion, there we find the fibres multiplied in proportion, and the space they occupy is skilfully economized by the oblique disposition of them already mentioned. In like manner wherever there is greater occasion for quantity of motion than for strength, there we find the fleshy fibres long in proportion. In a word, the strength of a muscle is as the number of its fleshy fibres, and the extent or range of its action as the length of these fibres." (*Exp. Anat., Tr. des Muscles*, n. 52—55.)

510. From the preceding remarks it follows, that the fleshy fibres in the muscles,—bound together and confined both lengthwise, and in respect of their transverse or oblique filaments, breadthwise also, and this, too, by particular septa,—are variously and wavily corrugated when constriction takes place, and at the same time harden and grow pale, &c. It follows also, that the nerve which is consecutively released from its envelopes, before it enters the muscular tissue fibril-wise, entirely loses the liquid it contained between its fascicles; which liquid, for the sake of distinction from the spirituous fluid, we shall call the nervous juice (n. 157). This juice, however, which is conveyed downwards, pumped upwards, and so circulated, passes for the most part through the periosteum into the vaginal tunic of the spinal marrow, and thence into each periosteum of the cranium, namely, the internal or dura mater, and the external.

511. We should also add, that while the animation of the brains coincides with the motion of the heart, as in the fœtus before birth, no muscular motion can be produced in the body except that of the heart, arteries and veins. In these there is no other species of motion than the most common and universal, that is to say, no other than the animation of the brains, with which at that time the motion of the heart coincides. For this reason all the nervous fibres at this period act alternately with the blood, so that when a fibre opens the pores of a muscle, the blood flows into them, and *vice versâ*; against this general cur-

rent, which is renovated both from the brains and from the heart, no fibre or cortical torus can rise or elevate itself. This is the reason why the circulation of the blood in the foetal state is successive, namely, from the brains, (which while they expel all the spirituous fluid through the fibres, expel likewise all the blood that is to pass into the body through the sinuses and veins into the heart,) through the vena cava superior, to the heart, &c. See Chapter IV. Should any muscle at this time be constricted by itself, or rise separately, the entire current would resist it, not only the current in the fibres, but also that in the vessels, for it would be attended with a loss of the successive circulation. As soon therefore as this begins to take place, or as soon as the muscles attempt to act individually, the change which arises incites the foetus to pass from the womb into the open air, in order that the circulation may be inverted with safety, through the medium of the lungs. When this inversion of the circulation is accomplished, and the animation of the brain is no longer synchronous with the pulsation of the heart, and when every particular as well as general animation sends the blood down from the motive fibres of the muscles into the vena cava, then the fibre is able to act against the blood, and the blood against the fibre, the internal cause against the external, and the external against the internal, and each viscus respectively is excited to motions corresponding in character to its acting causes.

But these principles of muscular motion may be more accurately shewn from the various modes in which the heart acts through the medium of the nerves upon the muscles, and through the muscles upon the enclosed blood; and *vice versâ*, through the blood upon the nerves, and hence through the nerves upon the muscular fibres. Now that we are furnished with these principles, let us proceed to investigate the proximate and remote causes of the motion of the heart.

512. *After a due consideration of these subjects, we shall learn, that the proximate cause of the heart's diastole, is the continual pressure and action of the blood of the two venæ cavæ upon the right auricle; and that the proximate cause of the heart's systole is the extension of the nervous fibres: so that when the blood acts, the nervous fibre yields; and when the nervous fibre acts, the*



*blood yields.* For the sake of inexperienced readers, I will first of all give a short account of the alternate motion of the auricles and ventricles; and as Boerhaave supplies us with one which is very clear and succinct, it will be sufficient to cite his words. "Both the venous sinuses," says he, "are filled, turgid, and red, at one and the same time; and so are both the auricles. Both the auricles become flaccid at the same instant, and so also do both the venous sinuses. At the very moment that the auricles become flaccid, they are filled with blood, by the impulse of that in the veins, and by the contractile action of the adjoining muscular venous sinus. At the same instant, both ventricles contract, are emptied of blood, become pale, and the two great arteries are filled and dilated. At the moment after this constriction, each empty ventricle is flaccid, elongated, and reddened, and its cavity enlarged. Scarcely has this happened, when both auricles, and both muscular venous sinuses, contract with a muscular motion, express the blood they contain, and propel it into the ventricles; and now the auricles become pale" (n. 460, p. 429). Thus the motion of the auricles and ventricles is alternate; so that when the auricles are compressed and emptied, the ventricles are filled with blood and expanded, and *vice versâ*. It is likewise to be observed, that as soon as the auricles are filled and expanded, the two arteries, viz., the pulmonary artery and the aorta, are also expanded, so that the whole sanguineous system depending upon them comes into a state of dilatation in concert with the auricles, the ventricles alone at this time being compressed. For the sake of a clearer apprehension of the subject, I will with Lancisi call the larger belly of the auricle its caudex, or with Boerhaave term it the venous sinus: but where this part is contiguous to the vena cava, I would call it the vestibule or upper vault, for it is from this point that it enlarges into a sinus. But the auricle strictly is that fimbriated part that projects beyond the base of the heart, and forms a fringed border, and as it were a pectinated crest. But as these particulars belong merely to the science of anatomy, I shall not any longer detain the reader on this part of the subject, but immediately proceed to elucidate the cause of this alternate constriction and expansion.

513. That the sole proximate cause of the expansion of the

auricles, is the pressure and action of the blood of the vena cava in the vestibule or first entrance into the auricular sinus or caudex, is abundantly proved by experiment. "In the vivisection of fowls," says Lancisi, "we saw a vermicular motion in the branches of the cava frequently recurring, followed at length by a slow contraction, or fluctuation, of the ample right auricle and ventricle, although there was no spontaneous stroke or pulse in the left auricle; and when the left ventricle was laid back, we could observe no motion in its posterior wall; although the segments of the heart moved when punctured with a needle; a sufficient proof, that the occasional cause (as they say) of spontaneous tension in the right auricle and ventricle, consisted in the powerful pressure of the blood, which was urged towards the right chambers of the heart by the branches of the cava peristaltically contracting" (n. 465). And Steno says: "When the three branches of the cava were tied, and all the blood that was within the ligature, in the cava and right auricle and ventricle, was let out through a little opening made with a fine needle in the bottom of the right ventricle, all motion ceased at once, and one would have said that the whole of the parts were dead. But this state of rest did not continue long, since the fresh blood issued from the veins of the heart, and slightly distending the collapsed tunics, produced a fresh but slight motion, which was however conspicuous in the cava alone. Nevertheless, when the ligatures were removed, and the blood could freely return to the heart, the motion of both the cava and auricles was restored immediately" (n. 466). That the sole proximate cause of the expansion of the auricles, is the pressure and action of the blood of the vena cava in the vestibule or first entry into the auricular sinus, becomes still more clear, when we consider that the motion of the heart can be resuscitated after death by injecting either blood or warm water into the vena cava, or into the subclavian or jugular veins (n. 467). From these various circumstances, Lancisi comes to the following conclusion. "Since it appears from experiment, when the ligatures on the vena cava are loosened, and the blood consequently flows through the usual channel into the right auricle and ventricle, that the motion returns spontaneously to the cavities of the heart; while on the contrary, when the blood is stagnant in the



pulmonary vein and left auricle, in consequence of the suspension of respiration, that the motion of the left auricle, and a large part of the left ventricle, immediately dies; we may most unhesitatingly conclude, that the blood is the proximate cause of the pulse of the heart. But on this fertile subject, let us come to a short statement, and content ourselves with declaring, that two principal things are necessary to the natural motion of the heart, namely, the action of the nerves, and the action of the blood." (*De Motu Cordis*, &c., lib. i., prop. 56.)

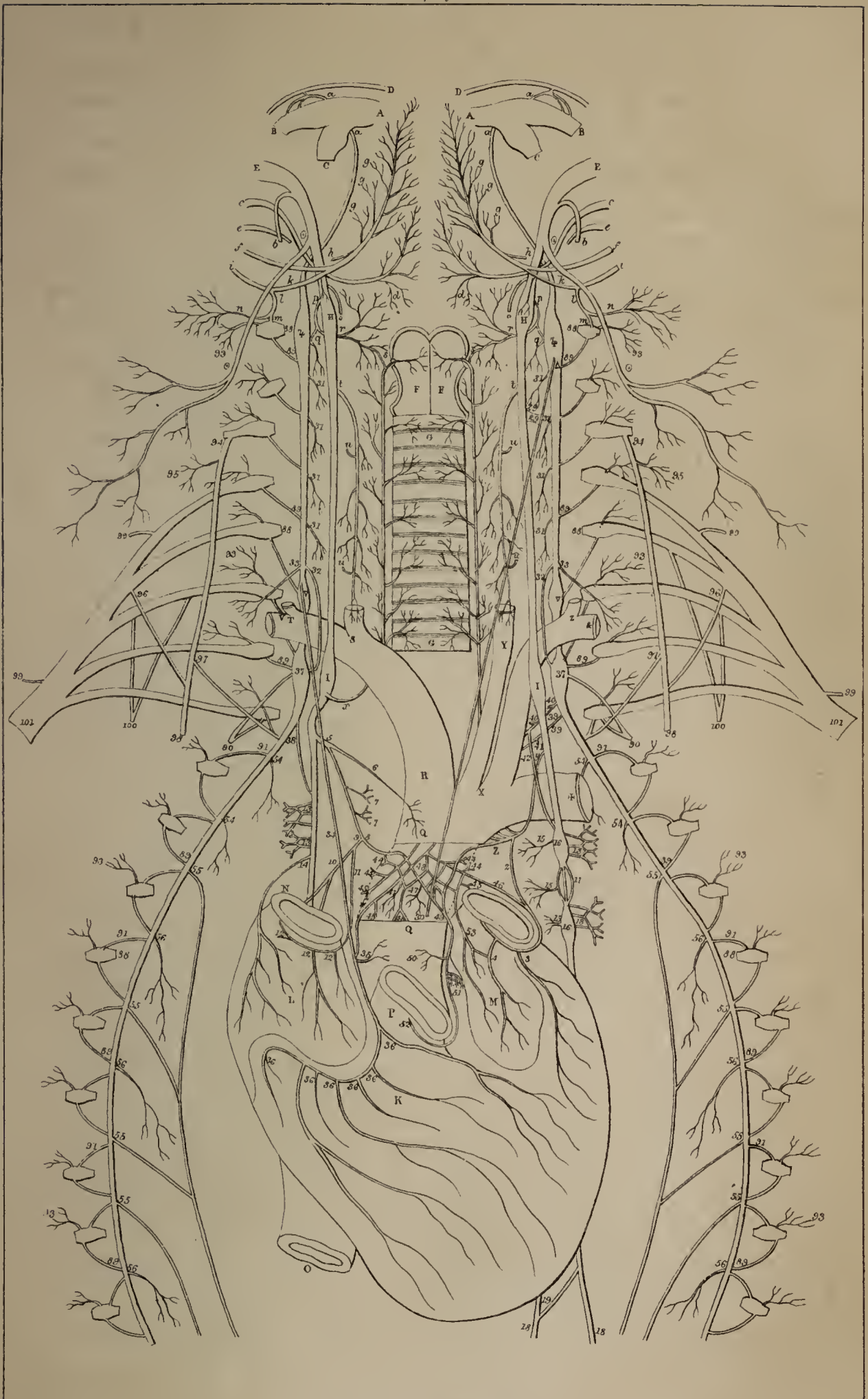
514. The manner in which the venous blood, simply by its pressure and action, is enabled to occasion these alternating motions, is purely mechanical, the nerves producing the effect by their alternate relaxation and constriction. Nothing is more common in mechanical experience, when alternate motions are to be produced, than the employment of a single force acting with the most perfect constancy. Thus in the case of automata, we use the spring or pendulum; in machines of other kinds, the wheel or lever, whether turned by water, wind, cattle, or any other power. The motion of this produces that of the other parts of the machinery, and thus through the medium of pulleys, wheels, levers, &c., we cause reciprocal actions of the original moving power. With ingenuity much greater, the same thing is effected in the machinery of the heart, where numerous fibres are arranged with all the science and skill of nature, and receive their animation from the brains according to this arrangement; for the more numerous, the sounder and the purer they are, the better and more distinct is their mode of acting, and the more sure they are of producing the required effect, as we find to be the case during youth; for to the end that they may readily follow each other in due mechanical order, they are so compounded, that upon the action of any given cause, every fibre, and particularly that which is dependent upon the par vagum, spontaneously rushes into such conditions as are adapted to ensure the conservation of the viscus, and the administration of the natural offices. Hence this machine is easily brought into the discharge of its alternate functions, for we learn from experience that the contact of a warm body,—the breath, the application of saliva on the fingers, of the point of a pen, and such like,—restore the whole machine

to its motion. The only requisite therefore to produce this alternate motion, is a pressing or acting force in the vestibule or threshold of the vena cava at the auricle, that is to say, the venous blood, which attempting to flow into the auricle, as soon as enough is supplied for the influx, may excite the heart to its natural and alternate motion, and cause the diastole of the auricle, from which the systole of the ventricles necessarily follows, and *vice versâ*.

515. But before we attempt to explain to the reader the mode in which this is done, it will be necessary for him to familiarize himself with the accompanying plate from Vieussens, and to study it well upon the principles we have before premised respecting the causes of muscular motion (n. 508, 509). And we are to observe, that this plate represents the nerves that enter the substance of the heart; for as the author implies, they are seen when the anterior region of the heart is denuded of the pericardium and sanguiferous ducts. [See the Plate, K.] But the nerves delineated by Lancisi, *De Motu Cordis*, tab. i., iv., vii., are those that more especially occupy the surface, and enfold the coronary vessels; for the same author says, "The nerves that are sent over the external and anterior surface of the heart, descend along the outside of the pulmonary artery; but those that are distributed over the posterior surface, run at the side of the aorta" (n. 463, p. 435). See n. 501. Let us then confine our attention to the plate of Vieussens, in which we are to notice, that at the vestibule of each auricle, or at the place where the vena cava passes into the right auricle, and the pulmonary vein into the left, there are nervous rings or girths represented in the plate by figures 12, 12, 12, 3, 4, from which nervous twigs pass into the caudex or great sinus of each auricle, and which are at length taken into the muscular substance. These girths are as it were the stays [*stapides*] of the nerves and fibres which flow from the vestibule into the muscular texture. Hence when the blood distends the auricle, it acts universally upon all those twigs that depend from the stay; but it does not act beyond them, or upon the vena cava, in order that the portion of the vena cava or its sinus that extends from the vestibule, may be capable of being moved alternately with the ventricles. A similar nervous ring immediately



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Newbery litho Rathbone Pl.





under the auricle, surrounds the right ventricle, as marked by the numbers 36, 36, 36, 36, and from this ring, twigs and nervous offsets proceed, which enter the muscular texture of each ventricle, so that in this respect the law of action observed by the ventricles is similar to that observed by the auricles. This occurs, in order that when each ventricle is swollen with influent blood, the nerves likewise may be expanded, but yet not expanded beyond this subcincture, so that the ventricles may be allowed to be moved alternately with the auricles. For were there no such cincture, then, to the same extent to which the nerves are continued, would their turgescence and consequent expansion be continued. Hence we nowhere see that the twigs are conveyed from these cinctures in a contrary direction, or from 36, 36, 36, backward into the auricle. In this appears then to consist the astonishingly ingenious mechanism of nature, a mechanism of such a kind, that from the mere action and pressure of the blood of the vena cava, the appendices of the latter are brought into a state of alternate action. The means by which this is effected, deserve, from the importance of the subject, a still farther examination.

516. We have said that the cause of the alternate motion of the heart, is the action and reaction of the blood and of the nerves; that hence the proximate cause of the motion of the ventricles is the action of the blood and the nerves in the auricles, and the proximate cause of the motion of the auricles is the action of the blood and the nerves in the venæ cavæ. If now we wish to advance farther into the subject of the continuation of causes, it may be observed, that the proximate cause of the motion of the vena cava is each particular branch of it, the proximate cause of the motion of the branch is each particular twig of this branch, and each particular little tube thence depending, the proximate cause of the motion of each particular venous twig is the action of the smallest arterial vessel annexed to it (n. 222, 223), and the proximate cause of this action is the action of the branch, of the trunk, and finally of the heart; so that the cause of the motion of the heart is continuous, and describes a circle from the left ventricle through the whole sanguineous system to the right ventricle; hence there is no point in this system which does not contribute to the motion of the

heart (n. 234). Still, properly speaking, these causes cannot be called several, nor can they be called remote and proximate, because they are all in one continuous series, and being thus continuous, constitute, and as it were successively compound, the proximate cause of the motion of the auricle, and hence of the ventricles. Therefore, in order to know the proximate cause of the motion of the right auricle, we must first treat of the cause of the pressure and action of the two venæ cavæ.

517. With respect to the venæ cavæ, it is to be observed,

I. That they bear the same relation to the right auricle that this auricle bears to the right ventricle. II. Each vena cava is capable of vibrating several times while the right auricle vibrates only once, as the right auricle is capable of vibrating several times while the right ventricle vibrates only once. III. The vena cava superior acts as far as the nervous ring, 12, 12, 12, or to the vestibule of the auricle, from which a new mode of motion begins—a motion of the whole part that is commonly called the auricle. IV. The inferior cava acts as far as the mouth of the right ventricle, but not like the superior, to any distinct vestibule. V. Without such a different extension of the motion of the superior and inferior cavæ, the motion of the heart could not be continued. VI. The tunic of the vena cava makes common cause with the blood itself.

Let us now consider these particulars.

518. I. That the cavæ bear the same relation to the right auricle that this auricle bears to the right ventricle.—We mean in regard to the pressure, action, and influx of the blood, for the outlying blood\* of the vena cava incites the auricle to act, in the same manner as the blood of the auricle incites the ventricle to act, the only difference being in regard to space and figure. The auricle rapidly enlarges, from the culmination of its vault, into a large sinus or caudex, the vena cava likewise enlarges from a smaller dimension and diameter to a greater, but in a

\* Accubius sanguis.



conical form and by slower gradations. The nerves also flow through the surface of the vena cava in the same manner as through the surface of the auricle, namely, from stays placed higher up, from which the projecting twigs decrease all the way to the auricle, as we have above observed upon the subject of the auricles and ventricles (n. 515). Let us take for an example the vena cava inferior, on the fluxion of whose nerves Lancisi has the following remark: "From each of the five pairs of nerves . . . offsets are sent below the heart, and again ascend through the vena cava inferior all the way to the right auricle. . . . From . . . [the renal plexus] we see a number of twigs inserted into the inferior vena cava, and wonderfully ascending along its membranes, with an ivied twine, all the way to the right auricle. . . . The nerves recurrent from the phrenic pair along the cava, proceed as follows: large branches are distributed to the nervous centre of the diaphragm, and send evident twigs to the vena cava, at the place where it perforates that septum, which twigs ascend, together with the other nerves above described as recurrent from the lower belly, to the right auricle and ventricle. [That these twigs ascend] is evident, because their branches below the diaphragm are of comparatively large size, and gradually diminish as they ascend, till at length they are obliterated and disappear in the right auricle, and at the mouth of the right ventricle" (n. 463, p. 435). I have observed the same in the vena cava superior, where the descending branches are, but they go no farther down than the vestibule, or nervous cincture of the auricle, as marked in the plate by 12, 12, 12. The vena cava then has to the auricle a relation similar to that which the auricle has to the ventricle. For the action of each of these extends from every branch, in the same manner as the action of every branch extends from all the twigs of this branch through which the influx of the blood takes place. So that there are the same number of spheres, or if I may so speak, the same number of joints of motion in one continuous series, which constitutes the proximate sphere of the right auricle, or if you please, the proximate sphere of the right ventricle.

519. II. Each vena cava is capable of vibrating several times while the right auricle vibrates only once, as the right auricle is capable of vibrating several times while the right ven-

tricle vibrates only once.—For as I have said, the joint of the motion begins from the nervous stay, and terminates with the twigs of this stay in the muscular substance. According to this arrangement, every joint can severally exhibit frequent vibrations, as is testified by the experiments made by Steno, who says, that “While the right auricle was beating seldom and slowly, I saw at length a motion of the cava, both in the right and left branches, and after two or three pulsations of the cava, the auricle moved once, but not always in the same way” (n. 446, p. 445). And Lancisi says, speaking of vivisections of horses: “Sometimes when only punctured with a needle or with the point of a lancet, the intermitted motion is again renewed: and when the experiment succeeds, the cava (moving like the intestines) makes reciprocal peristaltic constrictions and vibrations toward the heart four or five times, while the right auricle performs a single contraction only once” (n. 465). A similar phenomenon occurs in the auricle, according to observations made by several, as by Harvey for instance, who remarks, that “While the heart is gradually dying, one may see it, after two or three pulsations of the auricles, sometimes in a manner wakening up and responding, and slowly and with difficulty performing or essaying a single beat” (n. 462, p. 432). Not to mention other anatomists, who have “observed, that where the current of blood through the lungs is interrupted, the right auricle has palpitated once, twice, thrice, or even five times, before the ventricle or heart had pulsated once” (n. 467). Hence it follows that,

520. III. The vena cava superior acts as far as the nervous ring, 12, 12, 12, or to the vestibule of the auricle, from which a new mode of motion begins—a motion of the whole part that is commonly called the auricle. IV. The inferior cava acts as far as the mouth of the right ventricle, but not like the superior, to any distinct vestibule.—This is manifest from the experience adduced (n. 518). For, according to Lancisi, the twigs sent up along the inferior vena cava “are obliterated and disappear in the right auricle, and at the mouth of the right ventricle” (n. 463, p. 435): but not so the nerves of the superior cava, which only reach the top of the vault of the auricle (n. 518). This is confirmed by the evidence of sense, for between the su-



perior cava and the auricle there is a plain tendon, of which we shall speak in the sequel, and which is placed here in order that some motion may commence afresh. But the case is not the same in the inferior cava, which keeps enlarging with one continuous belly from its superior part as far as the division of the two cavæ, and from its inferior part as far as the auricle properly so called and the ventricle. The action of the superior cava then reaches as far as the tendon of the vestibule, and the action of the inferior cava as far as the auricle itself or the mouth of the right ventricle.

521. V. Without such a different extension of the motion of the superior and inferior cavæ, the motion of the heart could not be continued.—The reason is, 1. Because the superior vena cava carries down the blood derived more particularly from the brains and medulla oblongata, and the inferior cava carries up the blood collected from all parts and corners of the body. The same quantity cannot flow through one cava as through the other; the greater quantity frequently comes from the body when the muscles are in strong reciprocation; sometimes, however, the greater portion comes from the brains, in which case were there no such diverse extension of motion as we have referred to, the quantity of blood in one cava would excite the auricles and ventricles to act more than the quantity of blood in the other. 2. In order therefore always to effect an equilibrium of the blood of either region, the inferior cava is so situated under the superior, that when the auricle is compressed, that part of the blood that does not flow into the ventricle, flows either into the inferior vena cava, or else prevents any flowing in therefrom, until an equation or equilibrium of the pressure of the blood flowing from each cava be obtained. 3. This was more especially necessary in the successive circulation of the blood existing before birth (n. 331—334); from this successive circulation the simultaneous circulation, which is subsequent to birth, is derived; so that all the blood of the veins then flows into the right ventricle, and all the blood of the body flows through the foramen ovale into the left ventricle. In this state, the action of the blood of the inferior cava was subject to the action of the blood of the superior, which would not have been the case if the inferior cava entered by a similar tendinous

threshold into the cavity of the auricle. 4. Even after birth, by means of this arrangement, the brains continue to exercise a regimen upon the auricle; a subject to which we shall again advert. Moreover we have shewn that between the vessels of the brain and the heart there is a threshold, but not between the vessels of the body, which immediately enter the heart as their own proper organ. 5. Thus we see in some measure how, when the right ventricle is filled, (as it is when the current of blood through the lungs is interrupted,) the right auricle beats from twice to five times, while the ventricle beats only once. This circumstance may often take place, and continue till the formation of an equilibrium between the cavæ, but beyond this period it cannot continue unless a passage be afforded through some foramen ovales or some superficial vessels (n. 445). 6. A more proximate cause, however, will be assigned in the sequel (n. 526).

522. VI. The tunic of the vena cava makes common cause with the blood itself.—For one is so suited to the other, that the tunic is the tunic of the blood, or of its mode of acting, and the blood is the blood of the tunic, and from the two combined results one single determination (n. 134, 135); so that by one we may judge of the other. As therefore the blood acts, so does the tunic; especially since the very nerves themselves enter the tunic, and dispose and impel it, at the same time as the blood, to act in such and in no other manner. That one is thus an assistant cause to the other, is evident from experience. Steno observes, that “in a young cormorant, . . . when the right ventricle was laid open, and emptied of blood, a motion still continued in the coats of the vein, although now completely collapsed, and the transverse fibres, one after another, were slightly elevated thereby, so as to present the appearance of a thread carried transversely over the vein, and proceeding towards the heart: this motion had not ceased at two o’clock in the afternoon, although I began the vivisection at nine o’clock in the morning” (n. 466, p. 446). How this is effected by the determination of the nervous and motive fibres, is best demonstrated from the anatomy of the auricle and ventricle: a similar phenomenon being seen in the auricle; for Steno again says: “Sometimes the motion crept in the border of the auricle, from



the inferior corner toward the superior ; sometimes the same border was moved in the contrary direction, or from the superior corner to the inferior ; sometimes when the border was entirely at rest, a contraction was observed in the middle plane as it were of the auricle" (n. 466, p. 445). Thus the manner in which the blood should act, must be determined by the tunic, and the manner in which the tunic should act, must be determined by the nerves. Hence when we say that the proximate cause of the motion of the heart is the pressure and action of the blood of the vena cava, we understand this vein taken collectively with its tunic, as we shall also do in the ensuing remarks on the pressure and action of the blood of the auricle. It is a question worth investigation, since all the branches appear simultaneously to appropriate to themselves the whole auricle, whether each particular branch influent into the vein, does not appropriate to itself some share in the plane of the auricle, as Steno's observation would seem to imply.

523. From these observations we may learn how the superior vena cava, and how the inferior, acts upon the right auricle ; for instance, that the action of each is not distinguished into intervals, but is continuous, and coincides, if I may so speak, with active pressure or living conatus. At first sight indeed it would appear, as if some vermicular motion, or some motion similar to that of the intestines, were in the cava itself,—a circumstance which we might infer from the experiments related by Lancisi, who says : " In the vivisection of fowls, we saw a vermicular motion in the branches of the cava frequently recurring, followed at length by a slow contraction, or fluctuation, of the ample right auricle and ventricle" (n. 465). And Steno says : " In a young cormorant, . . . when the heart stopped, the part of the auricle nearest the vena cava survived for a long time ; and when the auricle also was quite motionless, the cava alone beat below the heart, exhibiting two entirely distinct motions, one of which was seen on the outside, in the remoter part, the other on the inside, in the part next to the heart" (n. 466). But if we examine the causes of the action of the cava, we shall find that while the animal is alive, there is no such verminating motion in the trunk itself, for the inferior cava is incited to act by each of its branches ; the branches flow, or are inserted, into

the trunk at different distances from each other, neither does the blood rush into it from one branch at the same moment as from another, the branches being situated at different distances from the main trunk in different regions of the body; and thus the blood does not rush into the trunk from the iliac and other veins at the same moment as from the nearer veins, as the emulgent, diaphragmatic, intercostal, &c.; in other words, it does not flow at the same alternate moments from the muscular flesh of the thighs, legs, abdomen and breast, or from the psoas, iliacus, pectineus, triceps, obturator, serratus, or anconeus, at the time when either all or some of them act differently from each other at the mandate of the brain. Hence, inasmuch as the beginning of the motion of the vena cava originates from each respective branch, and the branches do not pour the blood into their vein at one and the same moment, it necessarily follows, that all the causes that effect the motion of the vena cava, are continuous, or make one common cause, which is one and the same as continuous pressure and action; hence also as the equation and general pulseless circulation of the blood in the veins (n. 190—198). The same thing takes place with regard to the superior vena cava, into which indeed the blood flows at stated moments from the brains and spinal marrow, but this action is reduced to one common action by the blood of those vertebral veins which come from the region of the neck, especially by the blood of the subclavian and axillary veins, which flows from the entire length of the arm in different ways, according to the different distances and actions of the muscles. This appears to be the reason why the jugular veins inosculate with the subclavian, and the azygos with the superior cava; for were the action distinct, the heart itself might be impelled to obey it, and to pulsate according to the animation of the brains. We must not deny, however, but that the greatest or proximate action proceeds from the blood that flows out of the jugular vein and vena azygos. If any vermicular motion proceeded from these, there would no longer be such a circulation as there is in the arteries, but in consequence of this kind of vibration, there would be a propulsion of the blood in the veins in every direction, and more particularly in that direction where an escape for the blood was afforded; as, for instance,



into the auricle, in order that an impletion of all the vessels, and an equation of the blood, might with the more certainty be obtained, and that the continuous action of the veins might itself be maintained under the auspices of a universal motion, as is the case with all the other organs of the body. To animals which are dead, or immediately after death, these observations do not apply; for in these, some branch or other inosculating with the vena cava still survives, and when it acts without the others, occasions a certain distinct motion, because it is not confounded with them, nor is it compounded by them into one general or common action, inasmuch as they are now quiescent. In the branches, indeed, into which the blood flows simultaneously from the most minute offsets, and at its own stated intervals (n. 516), it is requisite that such a motion should exist, but it is not requisite in the cava, which is not simultaneously impelled by different currents. This appears to be the reason of the phenomena observed by Steno and Lancisi: "In fowls," says Lancisi, "if the vivisection be rapidly done, we see as distinctly as possible a motion towards the auricle . . . in all the branches of the cava" (n. 465).

524. But let us approach nearer to the cause of the alternate expansion and constriction of the heart, and indeed of the alternate expansion and constriction of the right auricle, which now immediately follows. We have said that the cause of the diastole of the auricle is the continuous action of the venæ cavæ, and that the proximate cause of its systole is the action of its nervous fibres upon its muscular fibres. But how the blood reciprocates these actions with the nerves, is not easily comprehended, unless we have first learnt from Chapter V., how the blood of the lacunæ of the auricle is pressed into the fleshy ducts of the latter, thence into its motive fibres, and from both these into its superficial vessels, for all these particulars concur as associate causes to produce the effect of reciprocation, and indeed in such a way that when the common blood, or the blood of the venæ cavæ, presses forward and flows into the entire cavity of the auricle, the blood also which is proper to the auricle, and which is in its fleshy ducts, presses forward and flows into each of its motive fibres; all its parts being arranged to this end (n. 423, 427). For unless the blood proper to either

cava were pressing into the fleshy fibre at the same moment in which the common blood were pressing into the large cavity, the muscle could by no means become dilated, as may be seen from the principles before laid down on the subject of the muscles (n. 504).

525. It follows, therefore, I. That the field of action of the auricle is from the nervous belt 12, 12, 12, all the way to its extreme border, and hence that the auricle can be moved separately and alternately. II. That the cause of its diastole or expansion is the blood flowing in from the two *venæ cavæ*; into this state the auricle comes when its proper blood also attempts to flow from the fleshy ducts into its motive fibre, and the blood of the superficial vessels passes out through its coronary orifices. III. That the efficient cause of its systole or constriction, is, that the nervous offsets on the surface are expanded with the surface itself; the expansion taking place in a direction corresponding to the fluxion of the fibres. IV. But that the effect of this cause cannot exist before there is an abundant influx of the blood of the auricle into the right ventricle, or else of blood from some other source. V. Consequently that this reciprocation results solely, and almost spontaneously, from the pressure of the blood of the *vena cava*. Let us now consider these propositions in detail.

526. I. The field of action of the auricle is from the nervous belt 12, 12, 12, all the way to its extreme border, and hence the auricle can be moved separately and alternately.—This has already been shewn (n. 515). For the action of the nerve, because the fluxion of its fluid, as in the case of the arteries, is onwards along the branches, and therefore from the nervous belt to the extremities of the offsets. Consequently it extends also from every branch to the extremities of the branch, so that the common action of the auricle is subdivided into as many particular actions as there are shoots and twigs. This is indicated likewise by the natural vibrations of the auricle, for “the



right auricle . . . beats on being touched with a needle, and sometimes takes on a peculiar vibration; one portion frequently not vibrating with the portion contiguous to it, but the vibration sometimes following in another and remoter part" (n. 467). That the action of the auricle takes place thus divisively and conjunctively, is testified by its partition into winding portions. That such a mode of action should exist is moreover necessary, because the auricle ought above all other parts to be so mobile, that when it receives a general excitation to motion from the superior cava, it may receive a particular excitation to motion from every branch of the inferior cava; a circumstance which appears to be the proximate cause why the inferior cava enters the auricle without a threshold, differing in this from the superior cava (n. 521).

527. II. The cause of its diastole or expansion is the blood flowing in from the two *venæ cavæ*; into this state the auricle comes when its proper blood also attempts to flow from the fleshy ducts into its motive fibre, and the blood of the superficial vessels passes out through its coronary orifices.—At one and the same moment the following actions coincide with each other as conjoint causes; namely, the action of the two *cavæ* upon the auricle, the action of the blood proper to the auricle, or the blood of the fleshy ducts, upon the motive fibres; and the action of the blood of the coronary vessels of the auricle upon their orifices. Of these actions, that of each cava, and consequently the proximate cause of the diastole, is perpetual. Now it is from the efficient causes that the effect flows, namely, the influx of the blood into the auricle, the influx of the blood from the fleshy ducts into every motive fibre, and the efflux from the coronary vessels of the auricle through their orifices; whence arises the diastole proceeding from the continuous action of the *vena cava* (n. 514, 516). The action of the blood in the fleshy ducts, and its influx into the motive fibre, coincide with the diastole (n. 423—425, 427). And also its efflux from the superficial vessels through their orifices (see n. 427); all which takes place in such a manner, that when the influx or the efflux fails, no effect is produced.

528. III. The efficient cause of its systole or constriction, is, that the nervous offsets on the surface are expanded

with the surface itself.—This is self-evident, and is the case not only with the nerves which are collected into fascicles, but also with their twigs and most minute offsets, in order that the force of expansion may be distributed and duly proportioned to all of them. There is a traction or drawing of the nerve (n. 507. 6. 12; 508. 7). The spirituous and nervous fluid thus contained, is propelled by every point, and the fibre contracts (n. 230, 504, 516); and with the fibre, every arterial vessel that constitutes the motive fibre (n. 147, 152, 153, 230, 502, 503). Not only is this the case with the nervous fibres which enter into the muscular substance, but also with the nervous fibre of the superficial vessels, together with the vessels themselves (n. 426, 501), and which, taken collectively, constitute the whole of the surface. This however is only the cause of the systole; there is as yet no effect.

529. IV. But the effect of this cause cannot exist, before there is an abundant influx of the blood of the auricle into the right ventricle, or else of blood from some other source.—In the meantime, before the effect exists, the cause is in the effort to act (n. 304). As soon as the blood of the auricle finds an exit, the reaction and equilibrium, or that which suspends the effect, is removed. An efflux is afforded into the right ventricle, and this gives rise to the systole and constriction of the auricle. We have said there must be an influx into the ventricle of the blood of the auricle, or else of blood from some other source. For with regard to the latter, in some subjects there is an influx through the foramen ovale; there is an influx also from the superior cava, through the medium of the auricle, into the inferior cava, with a view to preserve the equation of the blood (n. 521. 5); hence the auricle may be constricted frequently, while the ventricle is constricted only once (n. 519). This is one reason why so many coronary orifices open into the auricle (n. 428, 429, 430). In natural action, however, the auricle alternates with the ventricle.

530. V. Consequently this reciprocation results solely, and almost spontaneously, from the pressure of the blood of the vena cava.—Because from what we have premised, it is evident,

That the systole of the auricle is the cause of the diastole, and



the diastole the cause of the systole: that the balance of motion is the surface, or the superficial vessels collectively: and that the perpetually acting power is the two *venæ cavæ*.

531. That the systole is the cause of the diastole, has been shewn; for by the systole the proper blood, which solicits every motive fibre to receive it, is expressed into the fleshy ducts, (n. 410, 412, 427). That the diastole is the cause of the systole, follows from this, that every nervous fibre then becomes expanded, and the expansion is itself the cause of the constriction (n. 528). That the balance of motion is the surface, or the superficial vessels collectively, is evident, inasmuch as during the diastole of the auricle these vessels are expanded in the same manner as the nerves, and their expansion is the cause of their reaction (n. 416, 426, 501). But the contrary is the case during systole (n. 424—427). Whether we say the superficial vessels, or the surface, it amounts to the same thing, for the superficial vessels are the surface. But that the perpetually acting power is the two *venæ cavæ*, see n. 514, 516, 527, and all the preceding articles. Hence it is manifest, that in the structure of the heart there is, as Boerhaave says, “a wonderful and occult propensity to perform reciprocal acts of systole and diastole, and this, not only during life, but even after death; nay, after the heart has been separated from the body, and even when it is cut in pieces” (n. 460, p. 427).

532. It now remains for us to explain, that the auricle expands and compresses itself in a direction corresponding to the fluxion of the fibres;—not only of the nervous fibres, but also of the fleshy, and even of the tendinous fibres, all of which, by their direction, determine and shape the space over which the motion is diffused, or in other words, prescribe the limits of expansion and constriction; for the nervous fibres act, through the medium of the white motive fibres, upon the fleshy fibres, and the fleshy upon the tendinous, in the same manner as causes effected [act upon their] efficientes. From an examination of the fluxion of the above-mentioned fibres, it is evident, that during diastole the auricle expands in breadth and length, and opens the entrance from the superior cava; and that during

systole, it constricts in breadth and length, as well as narrows the inlet from the same cava.

The auricle expands in each dimension during diastole: this is shewn by the motive fibres themselves, for we learn by actual examination, that there is a double series of these fibres, which pass in contrary directions into opposite tendons. When these fibres are expanded, they relax the parietes in similar directions, that is to say, lengthwise and breadthwise, as in the arteries and veins; hence when they are constricted, the reverse is the case.

During diastole, the fibres open the entrance from the superior cava: for the fibres, both nervous, muscular and tendinous, form a manifest sphincter, or as it were circular muscle, which is expanded, as it would seem, by (*a parte*) the vena cava; just as we find in the other sphincters of the body, through which, when opened, a passage is afforded, as in the case of the pharynx, gullet, pylorus, the orifice of the uterus, rectum, &c. This we may conclude from Lancisi's description. "In the first place, then," says he, "extremely minute, and intorted and agglomerated fibres, form in this situation a circular muscle, not unlike a sphincter. . . . From this the fibres are continued spirally (yet with some tendency to a circular course) toward the heart, decussating with each other, and become more fleshy as they proceed, until they are so mingled with other fibres, that are applied to the superior cava, as to constitute and comprehend within them that uppermost vault of the vena cava called by us the vestibule, and which is the commencement of the right auricle; which auricle these lacerti beautifully form by processes of divarication, multiplication, collection into unequal fascicles, and intermixture with each other" (n. 464, p. 437, 438). But since the definition of the expansion depends solely upon the direction of the fibres around the given cavity lined by them, it follows, that if we would know the true form of expansion, we must first examine the several layers of fibres, which, considering their great variety, would be a tedious undertaking.

In general we may affirm, that as the auricle constricts and the ventricle expands, a swelling is formed by the pressure of the blood at the confluence of the cavæ. This swelling Lancisi



thus describes: "Every time the whole quadricave muscle of the heart is strained and constricted, the auricles are seen to be depressed toward the base, and to descend; and the ventricles to be elevated toward the base, and to ascend; so that the body of the heart, which before was oblong, becomes nearly round and spherical" (n. 464, p. 443). But I intend to pursue this subject in the sequel, when I come to speak of the right ventricle, and where the researches of anatomists will materially assist us.

533. From what we have now premised on the subject of the right auricle, we may learn the nature of the reciprocal motion of the right ventricle, for this motion has the same relation to that of the right auricle, as that of the right auricle has to that of the superior cava; and the motive cause of the muscle of the ventricle has also a corresponding relationship: wherefore the laws recited with respect to the auricle are applicable also to the ventricle, for a nervous belt to the ventricle marked in the plate 36, 36, 36, 36, runs immediately under the auricle, from which belt the alternate vibration of the ventricle is externally deduced as from its stay or ham-string; hence I would here merely repeat the former statements, in their application to the ventricle. I. That the field of the action of the ventricle extends from the nervous belt, as far as its apex, and consequently the ventricle is capable of being moved separately from the auricle, and alternately with it. II. That the cause of its diastole or expansion is the influx of blood from the auricle. Into this state the ventricle comes, when the blood proper to it attempts to flow from its fleshy ducts into its motive fibres, and the blood of the superficial vessels passes out through their orifices into the right auricle and the aorta. III. That the efficient cause of its systole or constriction is the expansion of the nervous offsets on its surface, together with that of the surface itself, this expansion taking place in the direction in which its fibres flow. IV. But that the effect of this cause, or the constriction, cannot exist before there is an abundant influx of the blood of the ventricle into the pulmonary artery, or else of blood from some other source. V. Consequently, that its systole is the cause of its diastole, and its diastole the cause of its systole; that the balance of this motion, is the surface or the

superficial vessels collectively ; and that the common cause or power perpetually acting, is both the blood and tunic of the right auricle. VI. That the action of the right auricle and ventricle extends to the left ventricle, which is aided also by the action of the left auricle.

534. As there is a similitude and parallelism between the causes of the constriction and expansion of the ventricles, and those of the auricle of which we have just treated, I forbear offering further evidence in proof of the foregoing articles ; for I. coincides with n. 526 ; II. with n. 527 ; III. with n. 528 ; IV. with n. 529 ; V. with n. 530, 531 ; and VI. with n. 543, 544, below.

535. The only question which here merits consideration is, what is the mode of constriction and expansion of the right ventricle ; and what is the connection existing between the motions of the two ventricles : but this can be brought to light only by nicely separating the layers and planes of muscular fibres. Let us however investigate the fibres upon the principle that they elongate during diastole, and contract during systole (n. 230, 472, 504) ; for they are so beautifully combined and girt by vessels, that the entire expansion of the fibre is made to take a longitudinal, and not at least so evidently a lateral direction.

536. If then we investigate the motive fibres of the heart upon this principle, we have only to examine anatomically the direction of the fibres, and to deduce the mode of expansion and constriction geometrically and mechanically according to the given direction. For 1, the fibres, longitudinally extended, during systole, contract or elevate the muscle longitudinally, and *vice versâ* during diastole. 2. The fibres, obliquely extended downwards, contract the muscle in the same oblique direction during systole, and *vice versâ*, extend it during diastole. The two series of oblique fibres, at whatever angle they decussate, contract the muscle laterally, and elevate it longitudinally during systole, and alternately expand and extend it during diastole. 3. The transverse fibres simply contract during systole, and enlarge breadthwise during diastole, in the same manner as circular sphincters. 4. But the spiral fibres, whether they proceed in a single direction, or in a double direction, the one opposite to the other, make only a perpetually oblique plane during sys-



tole, and contract the muscle simply, and not with a spiral contorsion; while, on the other hand, they in like manner expand it during diastole. For this spiral form produces a power of extension and constriction easy in its action and almost unresisting. This may be proved even to ocular demonstration, by the little pipes which are carried round the heart spirally, and tumify at one and the same moment, (301, 302). 5. The tendinous fibres also act in general as the muscular fibres act in particular; hence wherever a more general action is required, or a simultaneous action of the particular fibres, in the place of fleshy we have tendinous fibres, combined and disposed according to their mode of acting; for the forces of the muscular fibres verge towards these tendinous fibres as a centre, in order that by means of the latter a common or general effect may result from a multiple and most distinct cause.

537. From a careful evolution of the fibres and fascicles and planes of fibres in the heart, we are led to discover its mode of expansion and constriction. Thus, 1, its ventricles expand in breadth and length during diastole, and constrict during systole. But this is not so manifest in the human heart as in that of brutes, where the heart does not lie upon the diaphragm as in man, for the human heart has seldom or never a perpendicular layer like the outer layer in the heart of the ox, &c., but it has common planes, which extend from the base, and from the division of the ventricles outwardly, and from their tendinous orifices inwardly; and these planes running obliquely in contrary directions, decussate variously, and while they constrict the muscle, slightly elevate it to the angle of their direction. The reverse of this takes place during diastole. There are also spiral fibres, and the oblique fibres that are round the cone, become spiral, and the more horizontally they run, or the more parallel to the base, the more do they narrow the enclosed cavity in breadth, and the less do they raise it perpendicularly. There are also transverse fibres which only constrict the sides during systole, and expand them during diastole. "This four-chambered muscle," says Lancisi, alluding to the heart, "is made and constituted of many rolls of fibres, some almost straight (as seen chiefly in brutes that hang down the head) and transverse, and others, and these the greater number, spiral, and

for the most part decussating with, and intersecting each other” (n. 464, p. 437). And Boerhaave says: “From these [the four circular tendons of the heart] arise, 1, a small number of slender fibres, which run in almost a straight line from the base to the apex on the outside of the right ventricle only. . . . 2. Underneath these, in the same ventricle, arise other fibres from the left side of the heart, which ascend obliquely towards the right side, take a spiral course, and terminate in the base. 3. Under the last fibres again, there are others which run from the right side of the heart to the left, encompass and embrace both ventricles, and rising to the base of the left ventricle, form a contrary spiral to the series mentioned before” (n. 461). We shall be better able to judge of this subject, if we consult the various anatomical plates in which the layers of the heart are shewn, and particularly the figures in Cowper’s *Anatomy* (tab. xxii., fig. 2, 3, 4, &c.). There is then during diastole an expansion of the ventricles, and during systole a constriction of the ventricles, and this takes place in different hearts in a greater or less degree according to the differences in the oblique or spiral course of the fibres. 2. There is also a direction of the fibres towards the apertures of the ventricles; for instance, of the fibres of the right ventricle towards the pulmonary artery, and of the fibres of the left ventricle towards the aorta; so that there are wedges of fibres that inflect themselves from the external surface to the internal, from which also they again return; they are aided moreover by other particular fibres, in order that the constriction of each ventricle may be in the direction of the common apertures; and they also inflect themselves from the orifices between the auricles and ventricles toward the surface, and are thence reflected. “These layers of fibres,” says Lancisi, “take a direction more or less inclined to the longitudinal diameter of the heart; so that some of them form [with it] an acute angle, some almost a right angle. But these as it were bound fibres, do not run so as to pass through the apex into the cavities, but they run back for the most part inwardly, but a little inferiorly, to the circular tendons placed at the base of the heart, from which they arose exteriorly, but a little superiorly” (n. 464, p. 439). 3. In like manner also fibres run from the auricles over the ventricles to the mouths between the auricles and ventricles,



on which subject Lancisi says: "The fibres [are drawn] from the external surface of the auricles, and of the heads of the veins, obliquely, and as it were spirally, through the external part of the ventricles, all the way to the apex: which fibres, consequently, always enlarged in bulk, make up the thick cortex of the ventricles. . . . But when the spiral fibres reach the apex, they make a single and loose turn upon themselves, and are carried inwards, and beautifully constitute the inmost surface of the ventricles, and especially of the left ventricle, together with their tricuspid valves" (n. 464, p. 438, 439). 4. There are also layers of particular fibres which are prolonged from their own proper and also from their general origin, in order to construct the fleshy columns or particular ventricles, being thence extended for the purpose of directing the blood into the fleshy ducts. "For it is evident enough," says Lancisi, "that the internal parts of the ventricles, and the tendinous cords of the above valve, arise from the same fibres of which the external surface of the ventricles is constituted. . . . The osier twigs which have begun to constitute the right sinus, for instance, when they have reached the septum, are there twisted, implicated and decussated, not in order to remain there," &c. (n. 464, p. 439.) This is done, in order that when the ventricles by means of their constriction propel the blood into the large arteries, they may likewise propel their own proper blood into the fleshy ducts, for they are compressed both in general and in particular toward the septum where the lacunæ open with their little ducts. "Certain fibres," says Boerhaave, "constrict the entire heart, . . . constricting both ventricles at once by pressing them against the middle septum, and drawing up the apex towards the base of the heart" (n. 461). Again he says, that during diastole "the distance between the base of the heart and the apex is increased, [and] the pressure of the walls on the cavities is taken off" (n. 460, p. 428). 5. We may conclude then, that there are as many particular directions concurring with the one general direction, as there are inlets and outlets of the blood, that is to say, as there are orifices, lacunæ, fleshy ducts, in a word, immissaries, commissaries and emissaries, or as there are arteries, and little arteries and viens, whatever be the direction they take. Whoever therefore would unfold the mus-

cular texture of the heart, and the motion arising therefrom, according to the foregoing rules, must have a distinct comprehension of all the channels, and the equally numerous directions of the fibres; otherwise the multiplicity of their particular windings will cause him to lose his way, and be to him an inextricable labyrinth. For the most particular fibres are so subordinated to, and coördinated with, the more general, that all of them simultaneously cause a general motion, like so many parts combining to form a compound. What a stupendous chain of connection is thus exhibited in the animal economy! Discourse as we may upon the subject, still, after all, what is said will be as nothing in comparison with what remains unsaid.

538. *The cardiac machine is so constructed, that its alternate motion depends upon, and is determined by, the auricles, and particularly the right auricle, as its wheel and lever; consequently upon, and by, the intumescence of this auricle, when the blood presses, acts, and flows in; and upon, and by, its detumescence, when the nerves are extended.* It was shewn above, that the heart is not unlike a machine put in motion by a lever, wheel, pendulum, or spring, and that on the motion of this alone, its appendages flow, according to rule, into their respective alternate motions (n. 514). That the diastole is the cause of the systole, and *vice versâ*, and that it is the surface only that acts as the balance of the motion (n. 530, 531). Also that the auricle cannot be constricted, unless an efflux be somewhere provided for the contained blood; this efflux naturally taking place into the subjacent ventricle (n. 529); that hence the ventricle is expanded when the auricle passes into systole, and that it is thus that the alternation of motion exists (n. 529, 533). But let us approach still nearer both to the manner and effect of the alternation.

539. I say that the right auricle is so constructed, that when distended with blood, it opens the orifice into the right ventricle. And together with the aorta, contributes to its diastole. Nay more, that it extends its power of action as far as the left ventricle; which ventricle must be constricted at the same moment as the right, but cannot be expanded unless



the left auricle comes to its aid. Let us consider these particulars.

540. The right auricle is so constructed, that when distended with blood, it opens the orifice into the right ventricle.—The systole of the ventricle is the cause of the diastole (n. 530, 531). But no effect follows the cause unless there be an influx of blood from the right auricle (n. 529). Now in order that there may be this influx, and that the effect may invariably follow the cause, the auricle, swollen to the proper mark with the pressure of the blood of the *venæ cavæ*, at the time of expansion opens the orifice of the ventricle. Because the fimbriated part of the auricle, which projects beyond the base of the ventricle when filled with blood, (for it has innumerable little trenches or receptacles for lodging the blood,) lays back or reflects the whole of the portion that is contiguous to the orifice, and thus by a species of resupination, draws back the circular tendon so as to widen the mouth proportionably to the degree of its expansion; thus the ventricle, merely on the completion of its systole, possesses an open passage for the influx of the blood. That such is the connexion between the auricle and ventricle, may in some measure be seen from the following by Lancisi: “[From the auricles],” says he, “bundles . . . [of fibres] are sent . . . both outwardly and within the cavities: and it is of these fibres that the compact substance of the ventricles . . . is made up. Thus a multitude of *lacerti*, partly divided into fascicles, arise externally from the auricles and heads of the veins; and after forming, by their greater mutual adhesion and contorsion, the loose round tendons of the heart, communicate and are continuous with the series of fibres that make up the external surface of the heart. In like manner more tendinous bundles are continued from the internal surfaces of the heads of the veins, and of the auricles, and compose the internal structure both of the tricuspid valves, and of the surfaces of the ventricles. . . . But all these things are so done, that the fibres inosculate by diversified and innumerable advolutions, the external fibres with the internal, and the internal with the external, seeming to constitute a Gordian knot” (n. 464, p. 438). This appears to be the cause of the opening of the orifice on

the part of the auricle, although there are a variety of other causes on the part of the ventricle; and these are employed not only in retracting the valves and opening the large mouth, but also in opening the smaller mouths that lead from the lacunæ into the fleshy ducts. But these causes so operate, that whatever contributes to a particular effect, contributes also to the general effect, for particulars constitute the general; as the curious enquirer may see, if while forming a particular idea of all the particular tendons constructed in the ventricles of the heart, he endeavors to comprehend them also under a general idea. On this subject Lancisi says: "These four tendons, disposed in the form of sphincters, and applied to the mouths of the heart, become converted into four other tubular and very long tendons, which are distributed throughout the body, and denominated arteries and veins. . . . When we open . . . [the] sinuses, . . . we then find within the ventricles eleven other tendons constructed with amazing ingenuity; some of them common to the ventricles and their arteries" (n. 464, p. 437).

541. And together with the aorta, contributes to its diastole.—The auricle contributes to it not only by the infusion of blood and the expansion of the orifice (n. 540), but also when compressed, by relaxing all the tendons continued from the vena cava, as well as from its caudex, into the mouths, tricuspid valves, and outside and inside of the ventricle (n. 540); thus in proportion as the auricle is constricted, it gives the ventricle room to expand, so that although the latter has an expansive power from the intrusion of the blood into the fleshy ducts (n. 527), this power is nevertheless restrained, and its effect suspended, in proportion to the constriction of the auricle. Moreover the ventricle is capable of being expanded in the same proportion in which its superficial vessels are enabled to discharge themselves through the coronary orifice of the right auricle. These vessels act as a balance to the reciprocal motions (n. 527, 530, 531), and are enabled to discharge themselves in proportion as the auricle is compressed (n. 428—430).

The aorta also contributes to the diastole of the ventricle. We may here refer the reader to our plate, in which L is the right auricle, QQ the aorta, P the pulmonary artery, 35, 50, nervous branches inserted into the coat of the aorta.



Now conceive the auricle with these two arteries as expanded ; it follows that the nervous subcincture 36, 36, 36, is rolled back by the border of the auricle, resupinated as it is, and giving inwards, and is raised by the aorta and pulmonary artery together with the whole cardiac plexus coming from the aorta, when the latter is expanded. For the plexus is placed between the artery and the trachea, and is connected to it by several branches. The consequence is, that the spirituous fluid, and the juice contained in those nervous branches, is expelled toward the twigs and offsets ; just as when the arteries are expanded, the blood is propelled toward the peripheries of the branches. Thus when the ventricle comes to be expanded, or what is the same thing, when the nervous offsets come to be filled with their own fluid and juice, at the same moment in which they are deprived of it in the systole, the spirituous fluid is pressed forward by the simultaneous expansion of each artery and auricle, from the plexus into the branches, to supply whatever deficiency may have been occasioned. We here therefore see the reason of this device of nature ; for instance, that the right auricle and large artery are placed as it were at the two extremities, the sanguineous wave first flowing into the auricle, and lastly flowing out at the artery, thus animating with their united forces the whole intermediate machine, with a view to enable it to reciprocate its motions, and to induce it to observe a constant habit of action.

542. The auricle moreover extends its power of action as far as the left ventricle.—This appears from the prolongation of the twigs from the nervous subcincture 36, 36, 36, even considerably above the left ventricle itself, so that a continuity of action proceeds from this subcincture, and so from the right auricle ; hence there is no similar nervous ring between the left auricle and its ventricle. This is shewn by the experience of Lancisi. “In the vivisection of fowls,” says he, “we saw a vermicular motion in the branches of the cava frequently recurring, followed at length by a slow contraction, or fluctuation, of the ample right auricle and ventricle, although there was no spontaneous stroke or pulse in the left auricle ; and when the left ventricle was laid back, we could observe no motion in its posterior wall ; although the segments of the heart moved when

punctured with a needle ; a sufficient proof, that the occasional cause (as they say) of spontaneous tension in the right auricle and ventricle, consisted in the powerful pressure of the blood" (n. 465, p. 444, 445). The motion of the auricle coincides completely with the fluxion of the nerves as represented in the plate, for it reaches to the extremities of the foregoing branches ; but there is another nerve with its branches, marked by figure 3 in the plate, which takes it up about the posterior part of the left ventricle, and which comes from the left auricle : for this reason it is, that no motion can be detected in the posterior part of the ventricle. There is a similar fluxion of the motive fibres, the general layers of which extend from the bottom of one ventricle over the other. There is also a similar fluxion of the tendinous fibres, which are continued from the right auricle to the left ventricle, and which Lancisi thus describes : "These cysts, which have a double cavity separated by a partition, are so framed, that the osier twigs, [to pursue the comparison,] which have begun to constitute the right sinus for instance, when they have reached the septum, are there twisted, implicated and decussated, not in order to remain there, but to be prolonged onwards to the opposite side, and to weave and environ the left cavity" (n. 464, p. 439). "If . . . the tendons that are continuous with the auricles and ventricles, be held up to the light, their structure appears like a web, composed of various planes of filaments going off in different directions. Thus on one surface the fibres run from the right of the auricles to the left of the ventricles ; but on the other from the left of the auricles to the right of the ventricles ; while many again pass semicircularly, or are otherwise dispersed in various ways without observing any ascertained law, and support and strengthen the proximate planes" (*Ibid.*, p. 441).

543. This left ventricle must be constricted at the same moment as the right, but cannot be expanded unless the auricle comes to its aid.—See n. 533, VI., 534. This action of one ventricle with the other, is in accordance with the connection of each with the nervous, fleshy, and tendinous fibres of the other (n. 542), as also with that of the fleshy ducts, and superficial vessels ; we find it likewise accordant with experience. It is in accordance with the connection existing between the two with



regard to their *nervous fibres*; for the same twigs flowing from the same subcincture, run forward over the left ventricle; whence the cause of the constriction of the left ventricle proceeds also from the expansion of the right ventricle (n. 542), to the aid of which the left auricle comes, when the latter pours in its blood; when the blood is not poured in, the ventricle remains in a state of constriction. It is in accordance with the connection between the *motive and tendinous fibres* of the two, as we learn from the experience already adduced (n. 542). These fibres pass in common from the right sinus over the left; wherefore when there is any expansion of the right ventricle, it is not succeeded by any expansion of the left, unless when the blood flows in from the left auricle; but there is only a constriction of this ventricle. It is in accordance also with the connection between the *fleshy ducts* of the two, the greatest part of which come from the lacunæ of the right ventricle; for there are but few in the left (n. 404, 406, &c.). The blood being pressed against these, solicits the fibre to receive it, and instigates it to perform diastole, in which function the expansive power of the heart itself consists, which power is thus seen to be no occult quality. But the fleshy ducts which lead toward the motive fibres of the left ventricle, in vain solicit and instigate the ventricle to diastole, when there is no influx of blood from the left auricle. The cause is indeed perpetually acting, but still it is followed by no effect before there is an influx of blood into the cavity of the ventricle (n. 529). The action is also in accordance with the connection between the *superficial vessels* of the two, which cannot equilibrate the blood, when there is no blood expelled from them by expansion, into the aorta, or into the right auricle. This we also learn from *experience*; as that of Fantoni (n. 323), and Harvey (n. 544). This is the reason of what we asserted with respect to the fœtus (n. 335), in which the circulation of the blood is successive, because the right ventricle of the heart can be expanded, but not constricted, before the left; so that the systole is simultaneous, but not the diastole.

544. From these considerations it appears, that the right auricle is like the wheel and lever of the whole cardiac machine, or like a crane or *axis in peritrochio*, and that the other parts

appended to them, are in a most surprising manner excited, each to its own particular motion, by the auricle alone, and that each also involves its own mode of coöperating: and that then all flow to and fro in the direct order of nature, and by a regular necessity, and this in such wise, that if the auricle stops, the entire heart ceases to act: hence the auricle is so connected with its ventricles, that when the latter are unable to reciprocate their motions, in consequence of any impediment to the entrance of the blood into the arteries, the auricle can nevertheless vibrate three, four, or five times, and thus, by perpetually repeated strokes, can excite the ventricles to coöperate with it (n. 519). From the plate we have given, it likewise appears that the auricle depends upon its own proper nerves; those, for instance, designated by the figures 12, 12, 12, which proceed from their trunk 8, 9, 11, as also from the branch 14, but not from that reflected from the heart, nor from the great cardiac plexus. The facts of experience plainly shew that such is the dependence of all parts of the heart upon this auricle. We may here indeed refer to the observations of Harvey, who says: "First of all the left ventricle ceases to beat; then the left auricle; then the right ventricle; and at last, (as Galen also observed,) when all the others have given up their motion, and are dead, the right auricle still beats, so that the life appears to remain in it the latest. While the heart is gradually dying, one may see it, after two or three pulsations of the auricles, sometimes in a manner wakening up and responding, and slowly and with difficulty performing or essaying a single beat. But we must particularly remark, that after the heart has ceased to beat, although the auricle still beats, if we place a finger upon one ventricle, each particular pulsation will be felt in the ventricles; just in the same manner, as we before said, that the pulsations of the ventricles are felt in the arteries; that is to say, on account of the distention occasioned by the impulse of the blood. And at this time, when the auricle alone is beating, if we snip off the apex of the heart with a pair of scissors, we shall see the blood flow out at every beat" (n. 462, p. 431, 432.)

545. *All the other parts are so mutually connected, that whichever comes into motion, contributes to its reciprocation.* We have already observed that the vena cava excites the auricle to motion;



that the auricle excites the right ventricle, and that the right ventricle together with the auricle excites the left ventricle (n. 543). The aorta itself and the pulmonary artery, by acting upon the nervous subcincture, serve as wings to the ventricles; thus they react in the same proportion as they are acted on, and when they drive their blood on into the subsequent vessels, compel it to precipitate its course into themselves from the antecedent vessels. Nay, more, all the little arteries proper to the heart—all the fleshy ducts—contribute to the reciprocation of motion; for these, as they receive the blood, each into its own little tube, impel the fibre to a reciprocation of motion; every superficial vessel also contributes in like manner to this reciprocation; so that whether we consider the heart as a whole, or view it as to its several parts, there is nothing but conduces to the general purpose of this reciprocation.

546. *Consequently each, together with the whole, is kept in such perfect equilibration, that the smallest thing inverts the hinge of the motion, and the resistance, which in the natural state is very slight, is easily overcome.* This is evident from the several articles contained in the present Part, since the diastole is the cause of the systole, and *vice versâ*, the systole the cause of the diastole, and the only balance for reciprocating the motion is that of the blood-vessels and capillaries of the surface, the resistance of which is immediately overcome, in order that ample room and liberty may be given for their blood to flow through the orifices into the right auricle, or into the aorta; and in case this be not given, it is provided that the blood shall be able to flow back into the cavities of the heart, lest the systolic motions should be suspended (n. 408—414).

547. But it may be objected that the resistance on the part of the aorta is very great; for instance, in passing from the left ventricle into the aorta, all the blood is pressed from a larger cavity into a smaller, and hence that the first wave is determined into its first motion by the whole arterial system, and that for this reason it is that the left ventricle is fortified with so strong and thick a muscle. In answer to this we observe, that if we rightly consider the actions of the heart, we shall find that there is not so great a resistance offered by the aorta as at first might be imagined; for not only does the aorta itself, by its expansion

and reaction, assist its ventricle to reciprocate its motions (n. 545), but also on receiving the wave, it accepts it as its own, and spontaneously, that is, by means of its muscular coat, propels the blood toward the extremities of the branches; thus whatever be the portion of the wave it receives, it expels it from itself, and by the force of the heart sends it away in the same order of succession in which it was first brought in; for every point in the artery is like a particular heart (n. 507, 570). The left ventricle, moreover, is endowed with its strength of muscle, only on account of the frequent changes in the equilibrium of the general pressure of the arteries, which changes are occasioned so many times in the course of a day or an hour by the affections of the body and mind. For when the arteries by these means are too much constricted, they refuse to admit from the heart so large a volume, and consequently, in order for it to pass through them, it must needs be first pressed over the aortic threshold; as in case of wrestling, fighting, panting, striving, and other different obstructions offered at different times to the passage of the blood. Moreover nature, or rather the formative substance or soul, (in which the first ends, as well as the middle and ultimate ends, according to which causes follow in provisory and given order till they arrive at the ultimate effect, are present and inherent, simultaneously and instantly) (n. 260), seems to have provided this strength of muscle to oppose the frequent changes of this kind, and in order that in the advance and decline of age, when the channels in the heart have a tendency to obstruction, and the fibres begin to grow tendinous and to decrease in purity, number, and integrity, the body may in no respect suffer from want of its usual supply of blood, but the heart may, by reason of its strength, continually have power to recover its equilibrium, and never experiencing any loss of its forces, may endure to the latest moment of life, and be the last organ to die. Therefore, according to our proposition, the resistance is easily surmounted, being in the natural state extremely slight.

548. *Again, when the same subjects are rightly considered, we learn what are the remote efficient causes of the heart's motion, namely, that the lungs, the cerebrum, the medulla oblongata, the medulla spinalis, and the cerebellum, are such causes. The prox-*



imate cause, as we before said, is the action of the venæ cavæ upon the auricle; the more remote cause is that which produces this action of the cavæ; that is to say, both the action of their blood and also of their tunics. Hence whatever contributes to the quality and existence of the proximate cause of the motion of the heart, which is the action of the cava, in the order of causes is the more remote. Thus if the muscular tunic be the proximate cause of the circulation and action of the blood, then the motive fibres, and consequently the nervous fibres constituting and determining the motive fibre, hence also the cerebrum and the cerebellum, are the remoter causes. Thus whatever is prior, superior, and constituent of the cause of a cause, or of the cause efficient of an effect, is in this respect more remote, and this, in an ascending and descending order. There are also causes more proximate and remote between things coördinate or belonging to the same degree, though properly speaking, this is only a successive continuity of the same cause; whence we have associate, administrant, and auxiliary causes. But to come to the matter in hand.

549. *The lungs, since they admit and transmit the blood of the right side of the heart, and keep the præcordia in the universal motion.* The lungs do not immediately cause the action of the heart, but merely allow the blood to be transmitted, neither does the aorta cause the action of the heart, but serves only to send out the blood. The pulmonary vein, and the action of its blood upon the left auricle, is the proximate cause of the diastole of the left ventricle, and consequently the associate cause of the diastole of the venæ cavæ; the primary cause being that which incites the right auricle to act (n. 542, 543). Thus the pulmonary vein is an administrant cause, and is brought into association with the cava, in order still farther to promote the progress of the blood that has once been sent into the heart. It is thus a primary cause in the series of those which propel the blood through the heart.

550. There is between the lungs and the heart a conjunction and relationship so intimate, that we may readily pardon the very natural error of those who presume that the lungs are a part of the proximate cause of the alternate motion of the heart; for the right cistern of the heart does not open except only into

the pulmonary artery, and so into the lungs; and again the left receives the blood only from the four pulmonary veins: so that the heart is held and embraced solely by the two arms as it were of the lungs; and consequently when its passages of ingress and egress are closed, or when the recesses of the lungs are constricted, the right ventricle beats in vain, and so does the left, which is now empty, if indeed it beats at all. Moreover the body of the lungs is so connected with the heart, that the muscular fibre of the right side of the heart does not terminate till it traverses the lungs and arrives at the left ventricle, besides which the inmost membrane of the heart invests the inmost membrane of the pulmonary arteries. The pericardium, too, as a distinct bag, invests the pulmonary vessels, and also the bronchial branches as far up as the surface of the lungs, and to the trachea. The heart, moreover, lies in a carved recess in the bosom of the lungs, and over the aponeurotic centre of the diaphragm, the peripheries of which are pressed and moved by the concave lobes of the lungs. Again, the outer membrane of the pericardium is continuous with the outer membrane of the transverse septum, and the latter with the mediastinum, in the duplicature of which the heart lies; hence it is continuous with the pleura, and all its processes and folds, and thus also with the outer surface of the lungs. Nerves also proceed from the plexus of one of these organs into the other. From this extremely intimate affinity, and if I may so speak, this consanguinity between the heart and lungs, we may naturally, as I have said, fall into the opinion that the lungs are a part of the proximate cause of the alternate pulsation or motion of the heart, when nevertheless the real fact is otherwise; for the reception by the pulmonary artery of the blood of the right ventricle, is the cause of the motion of the heart only in the same manner as the aorta is the cause, which admits the blood of the left ventricle; and as the pouring by the pulmonary vein of the blood into the left cavity, is the cause of the motion of the heart, only in the same manner as the vena cava which infuses the blood into the right sinus is the cause; with this difference, that the right ventricle acts upon the left, and not the left upon the right (n. 542, 543). Still, however, doubt is not removed until one perceives the proximate cause of the motion of the



heart to be the continual action of the venous blood, but not the alternate motion or conjunction of the viscus through which the afflux of the venous blood takes place, according to the several articles of our preceding inductions (n. 190—198, 512, 514, 516, 518, 519, 521—523, 526, 538—544, &c.). For this reason it is that the vibrations of the heart can be continued for so long a time without the respiration of the lungs, as in the case of the fœtus, of divers, of persons suffering shipwreck, strangled, or any obstructions in the gullet, windpipe, bronchia, as also in aquatic animals. These vibrations, however, would not occur if the lungs were the proximate cause of the reciprocal motion of the heart.

551. It is worth our while to enquire for what reason the lungs and the heart are so intimately conjoined, and in what respect specifically the lungs contribute to the motion of the heart. We affirm then that the heart, by the assistance of the lungs, is kept in the universal motion, or in the animatory motion of the brains, which produces the effect, that the fibre of the heart can nowhere be destitute of its spirit or life; this spirit being poured into the nerves at the time of the animation of the brains. But as this subject deserves to be treated separately, we shall here only recapitulate a few of its leading principles. 1. The animation of the brains is the universal motion of the whole body, and of all the nervous fibres which during animation are provided with their spirit or fluid (n. 38, 97, 148, 150, 151, 154, 325, 370, &c.) 2. The intercostal nerve is kept in this animatory and general or universal motion of the brains, (n. 483, 492). 3. Also the par vagum, which reduces all the subaltern motions of the body to this universal motion, (n. 493, 494). 4. The lungs are in the same universal motion, (n. 241 [?], 280, 283, 367—369,) in so far as the brains after birth relinquish their association with the heart, and conjoin themselves with the animation of the lungs. 5. Hence the motion of the heart, which is an inferior universal motion, must be kept in the same stream of motion, not as regards its own proper vibrations, but as regards the motion of its whole body, and more especially as regards the pericardium, through which the nerves are transmitted; so that the nervous fibre of the heart never loses its vitality for want of a due supply of spirits.

That the whole heart, while it is otherwise employed in reciprocating its vibrations and motions, is at the same time kept in this universal motion (n. 287), appears from the following considerations. 1. The intercostal nerve runs into this organ after issuing from its own most active ganglia which are in the universal motion. 2. The eighth pair of nerves of the head, together with the intercostal, constitute the great cardiac plexus. 3. This plexus is placed between the trachea and aorta, in order that as soon as it is moved by the aorta, it may also be moved by the trachea, which is continuous with the bronchia. 4. The pericardium is in such continuity with the mediastinum, pleura, diaphragm, and lungs, as to be kept entirely in the pulmonary motion, and hence in the universal motion of the brains. Consequently all the nerves designed to enter the parenchyma of the heart, as the intercostal, the par vagum, the consociated nerves also out of the great and small plexus, as also the phrenic nerve, (which is in the same motion, because it is in that of the diaphragm,) pass through the pericardium, and are attached to it as their fulcrum or stay; for from their respective attachments we may conclude, that the pericardium has a motion similar to that of the respiration of the lungs, or of the animation of the brain. This is the reason why the pericardium, when inclosing the veins and pulmonary arteries within a species of capsule, incloses also the bronchial branches a long way up; and also why it is kept with the heart in the duplicature of the mediastinum, and consequently within the continuation of the pleura; and why it is attached to the diaphragm. There are moreover many other circumstances clearly indicating, that when the heart performs its alternate motions, all the nerves form stations in the places where the universal motion prevails, and finally in the pericardium; because the latter most readily transmits the juice and spirit through the nerves in like manner and at the same alternate periods. 5. The reason why the pericardium is united to the diaphragm, upon which the more even portion of the heart's surface presses, while the case is different in brutes, is that the animation of the human brain is immensely varied and interfered with by causes proceeding from the will; and consequently by the same causes the respiration of the lungs is disturbed; as in the case of every effect operated by the will,—in the case of effort,



speech, &c. Amid so great a multiplicity of perturbations, the heart or its nervous fibre would entirely lose its vital fluid, unless its pericardium were closely attached to the other extremity, or the diaphragm, in which the general motion of the lungs terminates. 6. In the mean time the heart itself will lie within its own capsule in a state of perfect liberty, nor will it in any measure adhere with its ventricles to its pericardium. Were the case otherwise, the surface of the heart, together with its vessels and nerves, would be deprived of its function, nor could it vibrate achronously with the motions of the lungs.

552. But the case is different in the foetus, or before birth, for then the heart can execute its motions without the aid of the lungs, because no motion prevails but the universal motion. The heart itself also is kept in the same motion, for it beats in accordance with the animatory motion of the brains (n. 282, &c.). Similar also is the state of those whose lungs are not acting, and who still retain an obscure vitality,—of those who are in fainting fits, in trance, who suffer submersion or strangulation, and nevertheless recover; in fine, who labor, from whatever cause, under any obstruction of the lungs: we may add also the case of certain animals which pass the winter without respiration. In all these instances the motion of the heart again unites itself with that of the brains (n. 285). Without this reunion, when the assistance of the lungs ceases, the heart could not possibly outlive the lungs. For this reason its life may be conjoined with insensibility and inaction of the muscles, or with privation of the voluntary and particular action of the brain.

553. *The cerebrum, since it propels its blood towards the jugular veins by its own proper force, and sprinkles into it the spirituous fluid, and acts moreover upon the muscles of the body.* These causes are remote, for they constitute the very pressure and action of the blood of the venæ cavæ, which is the proximate cause. When the circle of the blood through the arteries and veins by means of the heart is once begun, it cannot be continued of its own accord; in other words, the motion once impressed cannot become perpetual, and in consequence of a single impulse perform perpetual circles. For no effect operates long, by reason of its own proper force, as the continuous cause of a succeeding effect, unless its force be borrowed from some other

cause, and in the present case from one that is superior or prior. Without the persistence of the efficient cause, or without some alternate excitation, and consequently a restitution every moment of the loss of motion sustained, no motion would continue, but must constantly tend to stop. Hence the reason for the continuance of the motion of the heart, must be sought for in a higher principle, namely, in the brains, which act upon the muscular fibres of the heart, arteries and veins, and transmit their blood by their own proper and living force into the superior cava. Such then being the offices of the brains and spinal marrow, let us next explain what each specifically contributes to the motion of the heart.

554. With reference to the cerebrum we may observe, that by its own proper force it propels the blood toward the jugular veins; not indeed into the veins themselves, but from the sinus of the falx into the lateral sinuses, in which the blood is submitted to a mixed action, namely, the action both of the cerebrum and of the cerebellum, by which the blood is forwarded into the before-mentioned veins. The cerebrum moreover derives all the blood which flows in its different penetralia, as its ventricles &c., into the fourth sinus, where likewise the blood is received by a mixed action, namely, the action of the cerebrum together with that of the cerebellum, by which also it is propelled still further. Meanwhile this action is the cause of the motion of the heart considered as arising from the blood, because the blood is transmitted by the force proper to the brains through the jugular veins into the vena cava, since it is the part of the brains to act upon their own proper blood. This derivation of the blood from the brains toward the heart, may be called a living fountain, for as often as it takes place, it excites the circulation, without which action the circulation after a few turns would spontaneously cease, because it has a continual tendency to stop. It may indeed in some measure be compared with a wheel, which after being once set in motion, is made to continue moving by a series of perpetual impulses.

555. It is worthy of remark, that the cerebrum, with the aid of the cerebellum, determines its own proper blood more especially toward the right auricle, where lies the proximate cause of the motion of the heart: it determines it, for instance,



toward the right jugular vein, but not toward the left, which latter flows into the subclavian at a somewhat greater distance from the orifice of the auricle. For the great or falciform longitudinal sinus, which belongs to the cerebrum only, inflects itself for the most part toward the right lateral sinus, and carries thither the little canal grooved out on the occipital bone. "Out of fourteen subjects," says Morgagni, "which I examined successively, there were only four in which the lateral sinuses were a bifurcated continuation of the superior longitudinal sinus. . . . I observed that the sinus into which the whole longitudinal sinus is produced, is most frequently the right, for out of the remaining ten subjects there was only one in which it was produced into the left. Therefore in the left wall of the right sinus, as deflecting from the longitudinal sinus, the orifice was in some cases narrow, in others broad, in some double, and in some triple." (*Advers. Anat.* vi., *Anim.* 1.) The cause of this phenomenon is to be found solely in the place where the blood of the sinuses is finally discharged, since it is hence that the stream and connection of causes is continually flowing. For in the before-mentioned case, according to Eustachius and several other anatomists, the right jugular vein, which is a continuation of the right lateral sinus, and hence of the longitudinal sinus, approaches nearer than the left to the divarication of the subclavian veins, and pours its blood therefore more immediately into the vena cava and right auricle. Hence as the auricle is constantly requiring a fresh supply of blood, the nearest channels must pour in their own blood, and consequently, as being the nearer, the right jugular vein must pour in its blood before the left; and hence the right lateral sinus; and in the same manner also, by reason of its continuous connexion with the former, the longitudinal sinus. This order of fluxion is first determined in embryos, when the little canals of the fluids formed, and when the longitudinal sinus maintains the very closest connection with the heart, or when the heart is dependent upon the sinus, so far as it is dependent upon the synchronous motion of the brain. Hence it is that the right trunk of the par vagum, which by its emissary branches supplies the right auricle, and which also passes between the carotid artery and jugular vein, unites this vein so very closely to itself

under the appearance of a cellular, filamentary, and as it were membranous sheath. Hence also it is, that the left recurrent nerve, arising from the par vagum, inflects itself toward the larynx, and its muscles and rings, more suddenly than the right (n. 361). Moreover, the inferior or anterior surface of the cerebellum is divided, as we know, into certain protuberances or provinces, discriminated from each other by ridges. Now the larger of these protuberances, which lies under these transverse vermicular processes on each side, is formed into a variety of folds, which run in a parallel and transverse direction, and penetrate far into the compages of the cerebellum, in such a manner that the latter is insinuated downward more deeply on the right than on the left side. Hence the right portion of the transverse septum, or of the second process of the dura mater, when strongly agitated, deflects with its orifice and canal the blood which is flowing through it over the sinus, rather in this direction, or to the right, than in the other, or to the left. In the meantime, lest the equilibrium of the blood should be destroyed, the fourth sinus, with all its blood from the interior of the cerebrum, is drawn more especially toward the lateral sinus and jugular vein of the left side; hence there arises an equation of the wave; for which purpose also another short sinus is sometimes extended between the two lateral sinuses. In like manner there is a branch sent down obliquely from the right jugular vein to the left, where the latter inosculates with the subclavian; not to mention other communications for producing an equation of the blood, or supplying the deficiency of one part by the excess of another. In this manner there is an equation obtained not only of the quantity, but of the quality of the blood; for the blood which passes from the choroid plexuses through the fourth sinus, and for the most part discharges itself into the left lateral sinus, and consequently into the left jugular vein, does not seem to be so deprived of life as that which returns from the cortical substances of the brain, and which having as it were lost its vitality, runs into the longitudinal sinus. In the meantime, we may observe, that all these circumstances are but links in one and the same chain of causes, as is likewise the fact, that in man the azygos flows into the right cava; that the right lung, together with the right portion of the diaphragm,



exceeds the left in bulk and extent, which is only the continuous effect of one and the same cause, particularly as the lungs animate synchronously with the brains (n. 280, 283). Thus we see how the brain contributes to the motion of the heart, or to the motion of the right auricle, which is the wheel of the cardiac motion; we see it also in the fact, that the brain directs its blood for the most part toward this auricle.

556. It is likewise worthy of observation, that the brain pours into the blood flowing out by the jugular veins, a copious supply of spirit or spirituous fluid, which animates and vivifies the whole blood, and hence its whole circulation; for the blood may be so far called fluid as it is partaker of this spirit, since its fluidity is not owing to water or serum, but to this animal fluid, without which it would be altogether sluggish, lifeless, and incapable of acting and circulating. This is sufficiently evident from medical experience, as from the case of those who either labor under a deficiency of this fluid, or from indisposition by reason of its irregular commixtion or motion. In order therefore that the blood may be straightway made as fluid as possible, and that this may be effected in the heart, where the ingredients of the blood are first confused and commingled; that is to say, in order in this first and last stage of the circulation to prevent the blood from growing crude, and coalescing into irregular pieces, or into grumous, fibrous, indolent, viscid, and gelatinous substances, the brain immediately transmits a quantity of spirit toward the right auricle or entrance into the heart, for all the constituents of the blood where the proximate cause of the motion of the heart and the circulation thence depending exists; also at the same time toward that part of the subclavian vein where the new chyle issues from the thoracic duct. It is with a view to the performance of these highly necessary functions, that the whole cerebral laboratory for preparing and deriving this fluid, is provided. See n. 360, 361, and the Parts which will follow on these subjects.

557. To the preceding causes we may add another arising from the brain, namely, its acting upon the muscles of the body, and by means of this action propelling the blood into the two *venæ cavæ*. As this action is performed by means of a previous exercise of the will, there is thus in the brain as it were a living

fountain of motion, which continues the circulation by an actual inpouring of the blood. But still this is a very remote cause; for even when the muscles are at rest, as in sleep, the blood is nevertheless transfused from the whole of the muscular region into the vena cava. In the Part on the Muscles we design to shew, that when the muscle is relaxed, the blood flows through the communicatory vessels which we have called commissaries (n. 408—417), and that when it is constricted the case is otherwise. In the meantime it is a subject most worthy of enquiry, what is the state of the body, and what the state of the brain, during sleep, and wakefulness, and how the circulation of the blood is at these periods promoted in the brain and the body; for during wakefulness, an infinite number of channels are closed, which are open during sleep, and *vice versâ*. Every one may learn from his own experience, that the voluntary with the spontaneous natural power reigns universally during wakefulness, and these powers are frequently so mixed that we can scarcely distinguish the one from the other; as in the respiration of the lungs, in performing which the arch of the thorax is opened during wakefulness in a manner altogether different, and with different nerves and muscles from those which we find employed during sleep. The same observation holds with regard to other organs, so that it is at this period that causes are occupied in repairing all the losses which had occurred in causates during the day (n. 216, 217). But as this subject is of vast extent, and the enquiry into it supposes an investigation into the whole corporeal system; for one viscus sleeps and wakes differently from another; and as in different viscera the states of wakefulness and sleep alternate in different manners, (for the cerebellum and its nerves are more wakeful during the sleep of the cerebrum and its nerves than at other times, and likewise the whole of the natural economy depending upon the cerebellum,) I propose while I am upon this subject to say a few words respecting sleep, the cause of which I will endeavour to point out, having been led to it from the consideration of innumerable phenomena. Sleep, then, arises entirely from the influx of the red blood into the vessels of the purer or white blood in the brain, the consequence of which, is, that all distinction of degrees immediately perishes; for the



nervous or medullary fibre together with its fluid, cannot flow into a vessel of the red blood except through the medium of a vessel of the purer blood. When this happens in the brain, it necessarily follows that not one of its cortical tori is capable of a particular or individual elevation, nor can any one of the senses be, since a perfectly distinct subordination of degrees is required for their exercise; and when this distinction or discrimination is intercepted, the cerebrum can no longer apply its powers, but is bound to animate in common with the ever-wakeful cerebellum. Hence in those subjects in which a less distinction of degrees prevails, as in idiots, in persons sleeping, and the like, the will and sensation are always obtuse and dull in proportion. These observations however are only by the way, and are made merely with the view to enable us to deduce from known causes how each brain flows into the body at this time, and how the channels are opened into the vena cava, in order that the circulation may be continued. These, with a variety of other subjects, can never be traced up to their causes, or opened to view, without a distinct notion of the subordination and coördination of degrees.

558. *The cerebellum is a remote efficient cause, since it rolls down the blood, also by its own proper force, and so from a living fountain, into the superior vena cava; and fills and animates the cardiac nerves, and the nerves of the arteries and veins, with spirituous fluid.* The cerebrum is a more remote cause than the cerebellum, for the cerebellum more especially sends down the blood of the sinuses into the jugular veins, and at the same time transmits the nerves arising from its medulla, namely, the intercostal and par vagum, to the heart. With regard to the first statement, that the cerebellum sends down the blood of the sinuses of the head into the jugular veins, I observe, that *the lateral sinuses*, which receive the blood of the other sinuses, as the fourth and the longitudinal, are entirely under the rule of the cerebellum; they are carried down like an incurvated retort upon the petrous portions of the temporal bones, and attach themselves to the arm of the transverse septum or second process of the dura mater, which passes in a curve corresponding with the convexity of the cerebellum. Thus under the rule of the cerebellum, they are destitute of membranous expansions,

cords, sinews, folds, windings, and miliary corpuscles, and are invested with a coat of reticulated fibres ; so that when the cerebellum, by its alternate animation, moves about and presses their ventricose channels, the sinuses are themselves constricted, and are again restored on the escape of the blood. And the fourth sinus itself, which at one time we find at the head of the sinus of the falx, at another in one or other of its arms, generally in the left—at one time between both, at another opening sometimes with a single, sometimes with a double mouth—is recumbent upon the cerebellum, with which, along the greater part of its circumference, this sinus is in contact. But the cerebrum touches it only slightly in the commissure of the processes. The cerebellum also in a certain measure governs the sinus of the falx, for the sinus depends upon the falx, the falx upon the transverse septum, and the transverse septum principally upon the cerebellum. Thus we see that it devolves principally upon the cerebellum to forward the venous blood from the interiors of the head to the jugular veins, and also in some measure the blood of the ventricles of the cerebrum, of their choroid plexuses, and of the chemical laboratory both of the cerebrum and its organs. We see also that the cerebellum seems to be appointed to the office of the general administration of the functions in the animal economy, (while the cerebrum is employed in watching over the affairs proper to its own system), and more slowly and silently performs its animatory functions ; of all which subjects we shall speak in special Parts of our work. The cerebellum therefore, as far as regards the transmission of the blood through the jugular veins into the superior cava, is a cause of the pulsation of the heart, but a remote cause ; for the blood is expressed by the proper and living force of the brains, through the medium of as many corcula as there are simple spherules of the cortical substance ; the brains being the movers of their own blood (n. 219).

559. Moreover the cerebellum furnishes the heart itself, that is to say, its ventricles and auricles, the large arteries and veins, and for the most part also the minutest arteries and veins of the body, with nerves sent out from its medulla, namely, the intercostal and par vagum, which are the offspring of the cerebellum (n. 485, 490). Hence also the cerebellum provides the



heart with spirituous fluid and nervous juice, so that there is not a single point in the whole machinery of the heart, but is under the regimen of some peculiar fibre from the cerebellum; for in a muscle, and consequently in the body, the fibre with its fluid is all in all (n. 370); such also is the cerebellum in the heart. This is very evident from an experiment of Vieussens, who says of the dog, that “when the greater portion of the cerebrum is cut away, and the medulla between the cerebrum and cerebellum entirely removed, signs of life still continue in the motion of the blood and heart; and after the cerebrum is divided from the cerebellum and medulla oblongata, the animal respire for a considerable time, though not after the cerebrum is compressed by a violent percussion, nor does the heart move if the cerebellum be wounded, or cut in pieces, even should the cerebrum be left entire.”\* There is an experiment also by some one, in which a needle was thrust into the fourth ventricle between the first vertebra and the occipital bone, when the dog was immediately seized with three or four epileptic convulsions, and in a short time expired; the blood following the withdrawal of the needle, to the amount of about two ounces. See Manget, *Bibliotheca Anatomica*.<sup>s</sup> We should likewise bear in mind, that the cerebellum in the incubated egg appears to enlarge, and even to exist, simultaneously with the heart, as may be inferred from Malpighi’s observations (n. 242, 243). But although the cerebellum is all in all in the heart and larger vessels, yet it is only the remote cause of their pulsation, for it only produces the action of the blood, which is itself the proximate cause (n. 514, 516). To the cerebellum it is owing that all things in the body exist, subsist, and are capable of motion; not that they are put in motion by any act of the cerebellum, but that when put in motion, they are by its act continued therein.

560. In order that we may perceive how the cerebellum acts upon its blood, upon its fibres, and hence upon the muscle of the heart, it is my design to subjoin a complete description of the cerebellum; and this I will do the rather, as without a knowledge of it we cannot understand the mode of its influx into the

\* I cannot find this passage in Vieussens’ *Neurographia*.—(Tr.)

heart, which is the main subject here. With respect to *the external surface of the cerebellum*, we may observe, that as the cerebrum is divided by a membranous septum derived from the dura mater into two hemispheres, so also is the cerebellum, into which the beforementioned mater by a slight inflection makes its entry, distinguishing the right portion from the left. The superior part of the cerebellum, which lies immediately under the hinder lobes of the cerebrum, is in consequence more depressed and even, but the posterior and two lateral parts, turning suddenly, anteriorly, and inferiorly, narrow into a rounder and commonly a somewhat globular shape, while superiorly, under the second process of the dura mater, they run out into a more acute shape. The dura mater is superinduced over the cerebellum, beneath which, in close proximity with the brain, is the cellular membrane and pia mater. If we lay bare the cerebellum down to the pia mater, we then expose to view the surface and order of the small circles, with which the surface is ridged. In the superior plane of the hemispheres these divisive ridges or furrows are more distant from mutual contact, and more uniformly observe parallel lines. But as at the sides they run anteriorly, so on their way to the bottom of the cranium they approach each other, and at the bottom insert themselves into other fissures, which being as it were the roots of the superior, and more closely connected and enfolded, prevent the superior from being so divaricated as to make the interstices wider than they naturally are. These roots as it were of the small circles, after making wonderful inflexions and contorsions, end round certain slightly elevated protuberances, by means of which the furrowed surface is made to assume a certain lobular appearance. In these lobes, protuberances or subdivisions of the cerebellum, a different arrangement and order of the furrows prevails; an order running frequently in a contrary direction to that of those that extend from the general surface of the viscus to its margins. But still in every protuberance so called, they appear to approximate to a certain kind of parallelism. There are the same kind of subdivided surfaces of the cerebellum on each side round the medulla oblongata, the borders of which they closely touch; of these there are several, generally three pair. A larger on each hand, at the side of the corpora pyramidalia and olivaria, where



the nerves of the eighth pair issue out, and between the latter and the former, the nerves of the ninth pair. Into the surface the common or general circles wind sinuously from above, and from below wreath very deeply, and do not appear to preserve any conformity to the parallelism of the general circles of the superior surface, except in the interior of the cerebellum itself. Hence it is that the surface of this subdivision is ploughed up into ridges attached to the caudex of the medulla oblongata, which the nearer they approach, the more they recede from the circular shape, and follow the longitudinal course of the above caudex. The fellow to this larger surface on the right side is sometimes subdivided in a manner different from that of the former. At its farther limit it is marked with tortuous spires, and by means of intermediate articulations, so to speak, it is furrowed in a manner differently from the other; such is the way in which it seems connected with the common order and root of the circles. The other appendage of the furrows comes into view when a portion of the cerebrum is removed with the horizontal intervening septum near the annular protuberance, where the fourth and fifth pair of nerves issue from their original fibres. It is in a similar manner that these circles attach themselves to the margin of the abovementioned ring of the medulla oblongata, (taking a course conformable to its figure,) into which they obliquely flow from the common sphere of the circles. Intermediately and on each side a smaller surface projects, having lines observing the same order and direction as the former; namely, in the place where the annular protuberance ceases, and the pyramidal tail of the medulla oblongata receives it. This appendix is smaller than the others, and is as it were another vermicular but transverse process, which is articulated into all of them, having a more depressed fold surrounding it, which imparts to it a power of folding and unfolding with the neighbouring continuous ones. But these particular subdivisions of the cerebellum, with several others which are formed by small circles and surrounding corrugations, are not equally conspicuous in every subject. Moreover after the cerebellum has been spread out, and has experienced the effects of its own gravity, the corrugations are often unfolded and their discriminations obliterated, just as when a napkin twisted into spiral

folds is again unfolded, or as the forehead when contracted and wrinkled is again smoothed down and wears an even and serene aspect. The case is different with regard to the cerebrum; for even when it lies dead, it has the appearance of still furrowing itself, twisting and tying itself into knots, as if it were still on the point of forming sophisms. We would observe, however, that the cerebellum is such an articulated nodulation, such an intricate compages, as to baffle the research even of the most skilful anatomist, and not unless you convolve and twist it in a variety of ways, nor even then unless you liberate it from the pressure of the surrounding atmosphere, will you be able to survey it from its inmost principles, or to perceive from what particle of its cineritious substance the force and freedom of the animatory motion proceeds, in what manner it folds itself into its members, and unfolds itself from them. Some figures of its folds are given by Willis, *Cerebri Anatome*, fig. 1, 3, 7, 8: by Morgagni, *Advers. Anat.* vi., tab. i., fig. 3: and especially by Ruysch, *Epist. Anat.* xii., tab. xiii. xv.: and by Duverney, *Œuvres Anatomiques*, pl. 1. The cerebellum, however, although it seems discriminated on the surface into figures seemingly so various, as if traced by a compass, still has common or general circles knotted into a simple vermicular appendix. To the superior part of the cerebellum reach the circular sulci of the superior region; to the inferior part those of the posterior region. Hence it is that the appendix is double; there is, namely, a superior, which is larger, and an inferior, which is smaller. By means of a similar but very thin intermediate stratum, each appendix is bound as it were by a concatenated series and chain of circles. These vermicular processes receive from every quarter of the cerebellum the circles, which are thus concentrated in them out of the general compages, whence arise substances having the appearance of hinges furrowed transversely, and with small spaces left between the furrows, and numerous vessels. From these vermicular processes others are obliquely sent down, which are similar, and climbing upward form as it were little bridges, in order that the vermiform appendices may be accompanied by the little circles which creep along from each hemisphere in a waving, oblique, and lateral direction. But before the common or general circuit of the fur-



rows of the cerebellum passes into these appendices, it first insinuates itself into certain poles which are not far distant from the side of the appendix; for when this general orbiculation arrives at the border of the appendix, it traverses a certain centre, and by means of spiral circuits directs its course to a pole, out of which it passes by intervening appendices into the very vermicular parts themselves, so that the centre of the sphere of activity, or the cynosure of each hemisphere, is not in the above processes, but at the two sides. This may be seen in Eustachius, *Tabul. Anat.*, tab. vi., and in the plates of other anatomists. With respect to the *interior compages of the cerebellum*, we may observe, that, all the circles are surrounded by some common, elastic and cellular membrane, uniting together the duplicatures of the subjacent pia mater; if this membrane be raised from the subjacent one by the use of the blow-pipe, there appear in great beauty and exact order the discriminations formed by the little circles, and also little arteries disposed in a regular series, which passing into the beforementioned mater conceal within it their heads and capillary extremities, and thrust themselves out again into shadowy anfractuons little caverns, and transmit the blood, which has undergone its exertation, and is bereft of its spirit, into somewhat larger canals, and from these, by creeping along in a transverse, oblique and parallel direction, into the several channels and general sinuses. The pia mater itself, with the blood accompanying it, insinuates itself towards the interiors, in one place only to a short distance, in another more deeply, and for the most part in a falciform manner, which is seen when the superior region is bisected down to the vermiform processes. The duplicatures insinuated in one place unfold themselves and become even, in another are more intricate, so that their junctures are mutually dissimilar. The former, according as they are divided more obliquely or transversely, or more or less vertically, appear in the plate in shadow, and are capable of being divaricated in a larger or smaller plane, and are divaricable to a greater or less extent. The latter again, in the interior sinus of the cerebellum, pass off laterally and obliquely into smaller folds, and terminate only where the eye begins to lose the power of farther tracing them, or where the use of optical instruments fails. Thus it is that the attenuation and

expansion of the mater and blood-vessel, insinuating itself into the most recondite recesses, proceeds to an unassignable extent, so that it must be considered as a compages having throughout, from beginning to end, a connexion and contiguity, forming such a wicker tissue as to present a labyrinthine, and to the anatomist, completely inextricable knot, unless nature, while living in this her intricate abode, teaches him how to unravel her tissue in the same order in which she herself composed it. Wherever the reticulated texture of the vessels, and the sanguineous membrane, penetrate into recesses either visible or impervious to view, there also they are accompanied by the perpetually mobile, cortical or cineritious substance, which is moreover attached to them; so that such as are the implication, representation and influx of the foliated mater and reticularly complicated vessel, such or similar are those of the abovementioned substance; from this, as its parent, a white medullary substance is again everywhere educed, which procreated from the former occupies the interiors of the brain. If, therefore, the compages of the brain be cut through the middle down to the fourth ventricle, the form of a small tree—the arbor vitæ—makes its appearance. And if the brain be sliced obliquely in the direction of the same vermiform hinges, it displays similar boughs or branches; in this case the medulla, which lies more deeply inwards, is laid more open to view, because the trunks inosculate with the branches farther in; whence such as is the change in the obliquity or direction of the dissecting knife, such also is the change in the aspect of the arboreal formation. There appear to be three large medullary stems that inosculate immediately with the trunk just as it passes into the peduncle. The highest with its branches is single. The middle one is formed of two stems, to which belong branches which inosculate with it obliquely. In like manner the lowest grows out of two stems at the medullary centre, and possesses several conspicuous branches. So that there are as many principal trunks to this tree as there are medullary processes, besides innumerable smaller trunks which are implanted in the larger in regular order. If a horizontal section be made, the arboreal appearance is destroyed, and that of a variegated marble is assumed. We see also little diverticula for the blood, scattered like stars, and



red in hue. If the knife be passed farther into the substance, then after removing the little cortical and meningeal vaults, the spacious medulla is exposed to view without any interspersed and striated cineritious substance. The medullary stem, placed behind the medulla oblongata, buries itself as it were in its own soil, and by means of a flexure of the arch commonly over the middle ventricle, leaves a hollow; for where the stem grows into the medulla oblongata, it unites in one the medullæ of the roots, branches and boughs, it then separates into roots or processes, from which it sends down a larger one toward the testes, also another from the opposite side to the annular protuberance, which proceeding out of its own arboreal formation arranges the fibres for use in the most beautiful order, and folds in others from the cerebrum; it also sends down the restiform process from the same tree toward the spinal marrow. Thus the cerebellum envelopes the whole medulla oblongata, which is as it were stitched into it on each side by processes. But the utmost skill is requisite on the part of the anatomist, to find the direction in which the roots pass, and the circuitous course by which they dip into those that extend from the cerebrum to the spine. If the medullary trunk of the cerebellum be opened in such a manner that the branches are thrown to the margins, the medullary space is brought in view, with rhomboidal nets passing through it, and which space Vieussens calls the medullary centre of the hemispheres of the cerebellum; also the lesser tract which surrounds the fourth ventricle, and which is called the semicircular centre.

561. From these considerations it appears that the cerebellum is a unique and grand torus of cineritious substance, and acts in a manner peculiar to itself upon all its nerves, and by means of these upon its muscles. Moreover every sinuous constriction of this great mass takes a direction inwards only into the common peduncle, and hence into the processes into which it divides itself; for every eye of its tree has relation to its bough, every bough to its branch, and every branch to its twig; consequently every particle of cineritious substance has a relation to its own proper fibre, and every one of the fibres to the stem formed of the fibres collectively, which the cerebellum draws toward it during every constriction, possessing as it does

the faculty of adduction near the fourth ventricle, where its large peduncle passes; for the ventricle gives way on each side. From this, which is the largest nervous torus, we may see the mode of expansion and constriction of every smaller cortical torus of the brain, and which when cut represents in like manner the appearance of a tree, and in a smaller type maintains a resemblance to the larger one (n. 164, 505). But as the actual determinations of the tori of the brain are voluntary, and the things determined, or the actions in the body, are compound, the tori for this reason retain the voluntary form, and have that kind of connection with the proximate parts of which we have spoken, and send out a variety of peduncles, in order that the cerebrum may be able to act from its tori upon every individual peduncle separately; thus upon some of one and some of another torus, as also simultaneously upon all; so that from this simultaneous or successive action of several tori in different places upon their peduncles, the corresponding action of the body may be rendered compound (n. 287, 505). Now since the cerebellum, with uninterrupted constancy, performs its animatory motion in the one only manner proper to itself, and nevertheless transmits its fibre into all the viscera, each of which is moved in a manner different from the other, as for instance, into the auricles and ventricles of the heart, it is consequently necessary that the proximate causes of their action should proceed from the body (n. 506—508), and that the office of the cerebellum should consist only in preserving its nervous fibre whole and living; for the fibre dies, together with the motion of the viscus into which it enters, as soon as the cerebellum ceases to animate, or as soon as it is compressed, deprived of its blood, cut in pieces, or otherwise injured (n. 559).

562. *The medulla oblongata and medulla spinalis, since they transmit the blood into both venæ cavæ, and through the azygos particularly, into the superior vena cava.* How the spinal marrow, which is the continuation of the medulla oblongata, concurs with the brains to continue the motion of the heart, and what is the concatenation of causes from first to last, we cannot learn and demonstrate from any viscus better than from the spinal marrow, which is the distributor and mover of its own blood, and transmits it more particularly into the azygos, thence



into the superior cava, and in part also into the inferior. The spinal marrow therefore contributes to the continuation of the action and pressure of the blood of the two cavæ, and thus continues the circulation as it were from a living spring, nay, almost carries it on to its termination. In order to make this appear we must bear in mind that—

563. The spinal marrow is so connected with the cerebellum, and in fact with the cerebrum, that it is put in motion systaltically with each, and at the moment of such motion transmits its own proper blood, of which it is the mover, into both venæ cavæ, inferior and superior; into the superior, through the vena azygos, when the brains transmit their blood through the jugular veins. And in order that there may be a continuous chain of causes from the first to the last, the azygos is a single vein, and unites with the superior vena cava beside the right auricle, and is tied up to the trachea. Thus as long as the spinal marrow animates synchronously with the brains, and the lungs with both, the motion of the heart is necessarily continued. Let us now consider these positions.

564. The spinal marrow is so connected with the cerebellum, and in fact with the cerebrum, that it is put in motion systaltically with each.—This may be inferred from the continuity of the medullary and cineritious substance, and from the continuity of the membranes and of the blood vessels. It may be inferred, we say, from the continuity of the *medullary substance* of the brain; for this substance, crossing through the annular protuberance, passes straight to the anterior part of the spinal marrow, and that which comes out under the first process of the cerebellum, near the testes, descends also to the posterior part of the same. It may be inferred from the continuity of the *cortical substance*; for this is continued, distributed, and interwoven throughout the medulla oblongata, and finally is concentrated into the axis of the medulla spinalis, where it does not terminate till it arrives at the second lumbar vertebra. The same observation holds with regard to the cerebellum, all the

three processes of which run to the spinal marrow: the first from the region of the testes round the sides of the fourth ventricle: the second from the annular protuberance, where it turns in order to descend: the third or restiform process runs down evidently to the sides of the calamus scriptorius. This process does not pass out of the vertebral sheath till it has arrived at the os sacrum, whence it goes more especially to the members dedicated to generation, as shewn by a variety of proofs. It may be inferred from the continuity of the *membranes*, as of the pia mater of the cerebrum and cerebellum, which together with the arachnoid membrane proximately involves the same medulla: in the same manner it may be inferred from the dura mater, which extends to the ultimate apex of the os coccygis. It may be inferred from the continuity of the *blood vessels*, for the anterior spinal artery runs down from the vertebral united with it, and which is called the cervical, or from one of its crura, to the second lumbar vertebra and farther; consequently from the thalamus where the medullæ of the cerebrum and cerebellum unite. The posterior artery also runs down from the fourth ventricle and choroid plexus. Moreover the vertebral vein is common to both the medulla oblongata and to the superior region of the medulla spinalis; it passes likewise into the superior cava. Hence it follows, that such a connexion is established between the spinal marrow and the brains, that the former cannot be put in motion except synchronously with the latter. What the nature of its motion is, or of its expansion and constriction, is abundantly evident from its connection; that is to say, it is toward the posterior but not toward the anterior part of the spine; for between its pia and dura mater there extends from the large foramen of the occiput a space into which it can be expanded. There is also a groove or chink which runs through the dorsal region, and there the posterior spinal artery and vein are in their descent variously folded together, divided, and reunited. The action of the annular protuberance is immediately inflected toward the posterior region, where the fourth ventricle is, the expansion of which produces an effect upon the posterior part of the medulla spinalis, and lest this effect should extend to the anterior part, the precautionary means are used of a transverse cranny between the annular protuberance



and the corpora pyramidalia, and between the latter and the corpora olivaria. The spinal marrow is also very closely attached on its anterior part by means of its envelopes, where the spinal artery and vein is neither folded nor severed, and this is done with the view, that the first beginnings of the nerves which go out laterally may not be disturbed, and that every action of the marrow may be determined into the nerves, into the venous sinuses and their sinuli, and into their branches, just before the latter pass out of the cranial cavity through the same orifices as the nerves.

565. And at the moment of such motion transmits its own proper blood, of which it is the mover, into both venæ cavæ, inferior and superior.—That the spinal marrow is the mover of its own blood, just as the cerebrum and cerebellum are of theirs, is shewn by the continuation of the arteries and veins, as also by their attachment to its inner membrane; and indeed to its chinks and fissures, as on the anterior part. Innumerable capillaries run from the arteries into its proper cineritious substance, and from the same, innumerable offsets pass into the veins; and in the animatory motion are its proper cineritious spherules (which in the preceding pages we have compared to so many little hearts). In the same animatory motion is every capillary vessel; consequently all the various twigs, branches, and trunks. The twigs and branches are so carried through its integuments, and through the first beginnings of the nerves, that in whatever direction the action extends, they are in the very stream of its motion.

It transmits this its blood into both cavæ; for the venous vessels project themselves into the sheath, commonly in the form of a circular spire, always taking an exterior direction as far as the foramina, where they make their exit. The anterior spinal vein projects its branches no farther than into the internal part of the vertebral sinuses, after first perforating and slightly permeating the dura mater; but the posterior spinal vein, where the expansion and constriction of the medulla takes place, does not project itself into the vertebral sinuses, but beyond them; namely, into branches that communicate between the above sinuses and the vertebral veins, the azygos and cava. In its course it likewise receives small streams from the dura mater

and its ligamentary tunic; hence the spinal marrow, by a species of spire, or by that force of nature which is endowed with the greatest potency (n. 301, 302), acts upon the sanguineous streams just as they are on the point of departure from the vertebral sheath; and this, in order that its sphere of activity may extend as far as the superior cava and right auricle. Moreover, every vein is sent out from the vertebral sheath, through the same notches as those traversed by the spinal nerves; and in these veins, by reason of the reciprocal action, no other intervals of efflux and discharge can be assigned to the blood than those of the motion of the nerves that simultaneously pass out of the sheath, nor can any other intervals be assigned to the nerves than those of the spinal marrow, nor any other intervals to the spinal marrow than those of the cerebellum and cerebrum. We are here to observe, that the blood acted upon by the cineritious substance of the spinal marrow, which is most highly active, is derived from the cervical region toward the vertebral vein, from the dorsal region toward the azygos, and below, through the lumbar vessels, into the inferior cava. See Vieussens, *Neurographia Universalis*, lib. ii., cap. ii.

566. Into the superior, through the vena azygos, when the brains transmit their blood through the jugular veins.—This follows as a consequence from the preceding remarks; for while the spinal marrow, at the moments of its animation, is expelling its blood as far as the azygos, the azygos will at the same moments be receiving the blood thus expelled; and in order to ensure this result, the intercostal nerve is sent into all the branches of the azygos, and entwines them like ivy, as also the trunk of this vein, and soon after the vena cava; and while this nerve is kept in the stream of the motion of the brains (n. 483), so also is every branch of the azygos in the same stream of motion with that of the trunk; as appears from the fluxion of the branches of this vein along the ribs and pleura; from the situation of the trunk against the vertebræ; from its passage through the diaphragm; from its subnexation to the bronchia and trachea; from its intimate conjunction with them by the attachments of intervening vessels and fibres, so as to be filled and emptied exactly according to the times of constriction and expansion of the bronchia and trachea. Thus while the lungs perform their ani-



matory motion at the same moments with the brains, and the brains with the medullæ (n. 280, 283), the blood of the azygos is discharged into the superior cava, when the blood of the sinuses of the head is discharged into the jugular veins, and the blood of the jugular veins is discharged into the same cava. This is the reason why all the blood of the spiratory field of the lungs, or all the blood that flows from the muscles acted on in respiration, is derived into the azygos; and since the respiration is so varied (n. 368) that all the muscles of the thorax and abdomen may be called into action to elevate the lungs, this vein is therefore at the same intervals constrained to receive the blood from the intercostal, intracostal, infracostal, and supracostal muscles, and from all the vertebral muscles; from the triangularis sterni; from the serrati and pectorales; from the abdominal and diaphragmatic muscles, and consequently from the mammary, emulgent and spermatic veins; from the trachea, pleura, adipose membrane, &c.; in a word, from the whole field to which the pulmonary action extends, whether this action arise from a previous exercise of the will, or otherwise. This is the reason of the wonderful communication which these branches maintain with the veins of almost all the other parts of the body (and of which we shall presently speak); from which branches the blood flows immediately into the cava, when the respiration does not thus act; for the field of spiratory action extends to every part of the body (n. 367—369); as for instance, to the lumbar, uterine, and renal fields; to the neck, temples, and forehead; to the skin; through the diaphragm and other muscles, to the stomach, intestines, anus, bladder, pubes, lower ribs; or to every point from which, while the respiration is carried on, the azygos can draw the expressed liquid. Thus from the anastomoses of this vein with others adjacent and remote, we may infer, what was the natural and accustomed mode of respiration in this subject.

567. And in order that there may be a continuous chain of causes from the first to the last, the azygos is a single vein, and unites with the superior vena cava beside the right auricle, and is tied up to the trachea.—Before entering upon this subject, which touches very closely upon the cause of the continuation of the motion of the heart, I will give a brief description of the

azygos, compiled from Lancisi, Eustachius, Morgagni, Winslow, and Vieussens. The vena azygos, or vena sine pari, obtains its blood principally from the vertebral sinuses, the intercostal veins, the spinal nerves, and from a great number of muscles. In man it is a single vein, and placed on the right side, running near the vena cava and the right auricle of the heart; though in some subjects there is a lesser vein,—the semiazygos,—on the left side. The vena azygos is also single in the monkey, the dog, the horse, and some other animals. It lies on the left side in the hedgehog and the mouse. There are two veins corresponding to it, in the ox, the goat, and the sheep; also in the pig; but in the latter the left vein is so disposed that it receives its blood also from the lower ribs of the right side. In gallinaceous fowls there are four such veins, two on each side. The vena azygos of the human subject joins the vena cava outside the pericardium, and upon the right bronchium, round which it turns; it is also united to the trachea by strong fibres and minute vessels, which penetrate all the way to the internal surface of the latter. In the monkey, dog, and cat, it inosculates with the superior vena cava inside the pericardium, and near the right auricle of the heart. In the horse, it enters the base of the right auricle by one orifice; in the ox and pig, by two orifices, but which are only divided from each other by an intermediate muscular septum. In birds, all the veins answering to the vena azygos discharge themselves into the right and left axillary veins. The human semiazygos, when present, runs to the left subclavian vein. The vena azygos lies inside the thorax, opposite the roots of the ribs, along the right side of the vertebræ, and between the membranes of the pleura, [that is, in the posterior mediastinum.] It has valves, like other veins; and at its inosculation with the vena cava, it is furnished with a muscular semicircle or semisphincter, which is supplied by a particular branch of the spinal [intercostal] nerves. A similar muscular guard is observed in the semiazygos or left vein, when present, at the place where it joins the subclavian. At its lower end, the vena azygos sometimes communicates with the inferior vena cava, sometimes with the right emulgent vein, sometimes with one of the lumbar veins; and in its ascent it increases very greatly from receiving ten branches, into which,



and particularly the uppermost, subordinate branches run from the trachea and bronchia. On the left side it receives six or seven branches, the uppermost of which, insinuating itself under the right bronchium, and the great artery, at the left side of the thorax, climbs over the axillary artery, and ultimately falls into the left axillary vein. The fourth in order of the left branches [beginning from the lower end] is larger than the rest, and may be regarded as a little trunk of union; it comes originally from the testes, and in females from the uterus; and increases by streamlets joining it as it ascends. The vena azygos often joins the vena cava, at other times the emulgent vein, and the mammary veins; but it derives the greater part of its blood from the intercostal muscles, both of the right and left sides, from the serrati and pectorales, from the lumbar and vertebral muscles, from the diaphragm, up the side of which it creeps, from the sinuses of the spinal marrow, from the pleura, from the adipose membrane, from the sternum, and from other sources. Thus it receives nearly all the inferior intercostal veins of the right side, (which in their turn communicate with the rest of the thoracic, and with the mammary veins); also the left intercostal veins, though seldom the whole of them; for the superior veins run often to the left subclavian vein. Inferiorly, a branch of considerable size arises from the two last intercostal veins, and from those of the abdominal muscles, and rising to the vena azygos, unites with it about the last rib: and sometimes branches come from the straight lumbar veins, and from the inferior diaphragmatic vein. But the variety exhibited by this vein while it is forming its trunk,—the variety both in course and anastomoses,—is so very great, that it is not in our power to dwell upon all the particulars thereof. We must add to the foregoing, that this vein receives no blood from the three superior ribs, but for the first time from branches between the third and fourth ribs. It is well worthy of observation, that the intercostal nerve puts forth a trunk in the neck from both its inferior ganglionic plexuses, which trunk divides on each side into branches, about the fourth or fifth dorsal vertebra; and these branches afterwards again unite into one. They send out cords or fibres on each side, which in divers ways go to, cross over, and embrace, all the branches of the vena azygos, as

well as in various places the trunk of that vein ; and higher up, the vena cava ; and creep over the branches with erratic windings and ivy-like tendrils ; and after having thoroughly mingled, by minute twigs or fibrillæ, partly with the same intercostal veins, partly with the dorsal nerves, they perforate the diaphragm, and descending through the abdomen as far as the sacrum, put forth various twigs to the viscera, as well as to other nerves, and ultimately to the crural nerves ; and thus commix, by their fibrillæ, with nearly all the nerves proceeding from the dorsal spine.

568. From the foregoing observations and description we are led to see why the azygos is a solitary vein, and why it unites with the cava near the right auricle ; also why it is tied up and connected to the bronchia and trachea. It is a solitary vein, and is situated on the right side of the body, in order that it may pour all its blood immediately into the vena cava, where this vein is continuous with the right auricle, into which the jugular veins also pour all their blood from the brains ; to the end that the brains and the two medullæ, which also by a peculiar power animate unanimously and throw their blood into the cava, may all in common constantly excite the auricle to alternate motion. We see why it is connected and tied up to the bronchia and trachea, to which it is so united by inserted fibres and by vessels, that it can vomit out its liquid only at the alternate periods in which the lungs respire ; that is to say, in which the brains and medullæ animate. Thus there is a concatenation of causes from the first to the last, the last link in the chain being formed by this vein, which not only superadds the latest aid toward the continuation of the motion of the heart, but keeps all the causes in a state of concatenation and mutual connection by forming them as it were into a circle. In order, moreover, that the spinal marrow may assist in executing this task, it likewise transmits the blood from itself and from part of the cauda equina into the inferior cava, so that when the muscular fibre is at rest, the motion of the cava may be called into existence from a living source ; this likewise the spinal marrow is enabled to do from being placed in the ultimate boundary of the motion of the brains. Were there two azygæ or more, as in birds, then they could not be inserted into the trachea, but



on each side into the axillary, subclavian, or jugular vein, in which case the last cause would not correspond with the first, unless the vena cava ran in some other manner into the auricle; and that it does so may be demonstrated from the anatomy of birds. Thus the azygos itself confirms the fact, that the respiration of the lungs coincides with the animation of the brains (n. 280, 283); as also that in the foetus, before the lungs are opened, the heart so voraciously swallows the blood of the brains, and that of the spinal marrow, as to hurry all the blood of this vein toward the right auricle, which is the wheel of the cardiac motion (n. 514, 538, 544): nor does it allow of a semi-azygos inosculating with the left subclavian vein, except in those subjects where a due quantity of blood is poured into the subclavian vein from the jugular veins. Hence in those animals in which the azygos is double, we may infer that the greatest part of the blood of the longitudinal sinus is derived into the right arm of the lateral sinus, and hence into the right jugular vein. Whether or not this be the fact, the experience of another age will best ascertain.

569. *And it is not necessary, that the moments of animation in any of these parts should coincide with the alternate moments of the heart.* It is entirely the action of the blood of the vena cava, as exercised principally upon the right auricle, that produces the alternate motion of the heart (n. 514, 516). This action is continuous; in other words, the blood flows into the cava from one branch at periods different from those in which it flows into it from another; for instance, from distant branches at periods different from those of the proximate branches (n. 190—198, 523). The vena cava may vibrate frequently while the auricle vibrates only once, and the auricle may vibrate frequently while the ventricle vibrates only once (n. 519). Hence it is of no consequence at what moment the blood is poured into the vena cava, provided its action be continuous. The mechanism by which this is effected may in some measure be illustrated in the following manner. Suppose two bladders to be tied together, the one under the other, in such a manner as to allow of a passage from the upper into the lower by an intervening canal supplied with a valve. Suppose the lower to be furnished with a spring for compressing it, and also with a little tube for trans-

mitting the blood, just as we find it transmitted from the heart through the artery. If now the upper bladder be distended with liquid, and compressed, the liquid will flow into the lower, and these alternations will take place as often as the hand compresses the upper bladder. Now the bladders may be quadrupled so as to represent two auricles and two ventricles united as in the heart, between which a communication may be established by means of a canal. Thus when the two upper bladders are compressed, the two lower will be filled, and when the two upper are relaxed, the two lower will express their liquid into them through the intervening tubes. Moreover if we derive the water into the first bladder, which answers to the right auricle, through a long canal leading from some channel situated higher up, and indeed from a variety of orifices, consequently not at stated times, there will be a continual pressure exercised upon that bladder which answers to the right auricle, so that it will be only necessary successively to compress it, in order in this artificial heart to produce an alternate motion as often as we please.

570. A similar observation holds with regard to the nerves that traverse the surface of the heart, for it is not necessary that the spirituous fluid should be poured into them from the cerebellum at the same alternate periods as those in which the heart pulsates, but only that they be supplied with their juice at their own stated times, and be preserved in a state of integrity, just as we find to be the case in other viscera, as the *œsophagus*, stomach, intestines, liver, arteries, &c., which are in the highest state of mobility even after being separated from the great nerves (n. 506—510). For by the intumescence of the heart, the fluid is eliminated solely from those ultimate little branches of the nerves which are then extended, and into which when relaxed a fresh quantity flows from their larger branches and trunks; and lest there should ever be a deficiency of the supply to those offsets, it has been shewn that in the heart this supply has been provided for by the auricle and aorta in a peculiar manner (n. 541, 545). We may observe, moreover, that in the arteries (with which the nerves, or rather the fibres of the nerves, may be compared,) this may be proved to ocular demonstration (n. 472). For if the great trunk of the artery be taken,



and tied with a ligature between a given point and the heart, in such a manner that at any moment we may by slightly relaxing the ligature admit fresh blood into the trunk, then if we compress with the finger any branch of this trunk (while all the other branches are tied), or even if we compress the trunk itself behind the ligature, the blood will rush toward the extremities of the branch or branches (n. 178—181), and there produce its effect as often as we relax or compress the artery with the finger. The effect is the same whether the compression be made at the same moments with those of the motion of the heart, which is now as it were separated from the artery, or whether it be made *ad libitum* at any other time. Of the same kind also is the mode of acting pertaining to those nerves whose operations upon their muscles proceed from causes arising from the body (n. 506—508, 561). For in the doctrine of muscle, artery and fibre, the following rule is of the first and last importance, namely, that in every particular point of an artery there is a likeness of the heart, and in every particular point of a fibre there is a likeness of the brain, and this, in such wise, that there is no point in an artery and no point in a fibre, but propels its fluid, just as if the beginning were there, and the heart or brain most absolutely present. Wherefore when any point of a separated fibre is touched, compressed, or otherwise modified, a similar modification instantly flows along all the little succeeding branches to the extremities, with this only difference, that touch here modifies but a small number of branches; namely, those only which are below the point of contact; while the cerebrum or cerebellum modifies all universally, as the heart modifies all the arteries (n. 507).

571. *Since then these are the remote efficient causes, it follows; that the motion of the heart may be continued for a time without the assistance of any of them; but this time will be longer or shorter in proportion as the abovementioned bodies are in the series and connection of causes: in fine, just so long as the nervous fibres of the heart can be maintained in their integrity and power of acting, to preserve them in which is the peculiar office of the cerebellum; and so long as the blood can be poured from the living fountain into the vena cava. If it be asked by what connection of causes the heart may be enabled to continue its*

vibrations for a length of time without those primary sources of motion we have referred to, we have only to repeat by way of answer what we have before stated, that the motion of the heart may be continued, provided it has fluid proceeding from some origin into its nerves, and blood or some other liquid poured into its veins; and in order for this motion to be continued, it is only requisite that there should be some living fountain, which acts by itself; for the heart and its vein cannot act by themselves.

Among the wonders of natural and anatomical history, we find it told, that the motion of the heart may be continued after the cerebrum has been excised, and separated from the cerebellum and medulla oblongata; nay, after it has become absolutely hardened into stone. And that the same may be the case in subjects born without brains; and in insects after their heads are cut off. And finally in persons whose lungs have been long collapsed.

572. The motion of the heart may be continued after the cerebrum has been excised, and separated from the cerebellum and medulla oblongata.—This we find in the experiment made by Vieussens to which we have already alluded (n. 559), and where the reader may likewise see the causes of the fact; namely, that such is the connection of the cerebrum with the cerebellum, that although the cerebrum slowly and tacitly animates, especially in man, the cerebellum may nevertheless be expanded and constricted; and that the cerebellum extends its sphere of activity to the sinus of the falx, which sinus properly belongs to the cerebrum; to the fourth sinus, or torcular Herophili, which carries out all the blood from the penteralia of the cerebrum; to the region of the testes, nates, and pineal gland, or to the so-called isthmus of the ancients, but reflexively; nay, even to the organs of the chemical laboratory of the brain, and to the lateral sinuses, or first and second sinus of the ancients, both of which lie upon the cerebellum. Consequently as long as the cerebrum is at rest, the blood is poured into the jugular veins by the action of the cerebellum, whence arises that living spring



by which the motion of the heart is continued. The other parts through which the cerebrum and cerebellum communicate, such as the horizontal septum, the branches of the cervical artery both without and within the compages, the medullary processes and fibres in each portion of the medulla oblongata, are all so disposed, that the cerebellum is enabled to live for some time without the action of the cerebrum. The cerebellum does not communicate either with the cerebrum, or with the medulla oblongata, as to its cortical or cineritious substance, for this substance is not continued beyond the cerebellum; it is only the medullary substance which is educed continuously. In regard to the nerves, the cardiac nerves arise properly from the medulla cerebelli (n. 485, 490, 558, 559). Hence when the cerebrum has performed its last animation, the cardiac motion does not thenceforward expire. But for some time after the cerebrum has ceased its motion, or when it is too intent upon, or too distracted by, different objects, or has been very long in a state of wakefulness, its chemical laboratory of spirits will for the most part be at rest, and hence also the blood in the same proportion will be deprived of its fluidity and life (n. 360, 361, 566), will grow dry and heated, will run into fibres, grumous substances, crassamentum, and viscid matter; the consequence of which will be, a depraved chemical composition of the fluids, fevers, and a variety of diseases; also obstructions, inflammations, polypi, and various contagious disorders arising from malignant sanies.

573. Nay, after it has become absolutely hardened into stone.—Vallisnieri has published an excellent dissertation on petrified cerebra, under the title of, *Considerazioni ed Esperienze intorno al creduto cervello di Bue impietrito, vivente ancor l'animale*, &c., Padua, 1710. In this work he says, that the phenomenon of petrification in the cerebrum is not so rare at the present day; nor has happened only in France and Sweden, as T. Bartholin thinks, according to Sig. Verney. (Concerning the case of petrified brain extant in Sweden among the valuable collections left by Bromel, see the *Acta Literaria Sueciae* 1725, p. 90—98.) For a petrified cerebrum was found at Modena, which is represented in the above work, tab. i., and another shewn in tab. ii.; both of which the author describes:

the latter was sent to him as a present from Ferrara. He saw a third at Venice in the museum of Sig. Teta; a fourth at Bologna, in the gallery of Aldrovandi, and of which also he has given a figure. (*Op. Cit.* p. 22.) At Padua, according to many trusty witnesses, there is in the Monastery of St. Justina a concretion of the cerebrum of an ox. (p. 23.) He mentions, moreover, that a butcher residing at Modena, finding the cranium of a slaughtered ox indurated, sent him (the author) a message, and on opening the head he found the cerebrum entire, and in addition a kind of concrete matter, about half the size of the cerebrum, and fourteen ounces in weight, and which was smooth, shining, very hard, and nearly oval, and on the other side formed like a platter. On its surface the channels of the arteries and veins were visible, as they are seen on the concave surface of the cranium. On making sections of it, he found it as compact as a pebble, and white, but with some dusky circles, which proved *that it had been formed gradually*; the outer surface was crustaceous, but united to the inner substance, and distinguished only by its whiteness. It was very difficult to cut, requiring the same instruments as porphyry or jasper. On examining a small piece, it was evident that parts had been separated which were most tenacious and fibrous, just as in bone or hard wood, and yet which could be divided into smaller parts, like stones, but it could not by strokes be fractured into many smaller portions. When submitted to the action of flame, it became smooth, porous, exteriorly white and interiorly dusky, just like burnt bone. He adds, moreover, that the surface did not exhibit the serpentine flexures and furrows that are seen in the normal cerebrum; at least that they were not disposed in the common order; but that it displayed irregular tuberosities of various sizes. On the left side he observed a cavity with a tumor, just in the middle, which seemed like an old wound, &c. &c.

574. Since, then, in consequence of this induration, which commenced at the surface and extended successively, as is evident from the above description, the cerebrum had ceased to act upon its fibres, first desisting from particular, then from general animation, the cerebellum seems to have gradually assumed the helm of government, and by a process of successive inauguration, to have accustomed itself to the performance of



this office without the aid of the cerebrum; an office which it is the more enabled to discharge inasmuch as it carries on the greater part of its functions without the aid of the cerebrum (n. 572). In the present instance, moreover, there is such a reformation of the connecting links between the two, that when the cerebrum has grown completely torpid, the cerebellum, with the spinal marrow, has an acquired natural power of continuing this laborious office. Moreover the natural functions and actions, as of the heart, stomach, intestines and other viscera, are in the same connection with each other in the body, as are the crane, windlass, ropes, &c., with each other in an inanimate machine, so that when the rope is pulled, all the parts are set in motion, and produce their several effects; in the latter case, according to their artificial arrangement; in the former, according to their natural arrangement. Moreover it is only those causes that arise from the body that now (n. 506—508, 561, 570) put the machine in action; and this, too, as it appears, in an inverted order; such as the motions of the cheek, tongue, neck, thorax, arms, and feet, which nevertheless owe their first origin to the will of the cerebrum (particularly in man); and which, by usage, become at length so well disciplined, as to act upon the slightest notice given by any corporeal cause; for after the habit is acquired, they often return, as is well known, to their functions spontaneously, and without the consciousness of the cerebrum. This we see illustrated in the case of the tongue, either while it is performing its masticatory motion with the pharynx, or its locutory motion with the larynx; or in the case of the fingers sweeping over the strings of the lyre. When these acquired actions become spontaneous, they recur harmonically even when the cerebrum is almost asleep, or at least when it is unconscious. But who would believe that such a voluntary act becomes by habit natural and spontaneous through the medium of the medulla spinalis and medulla oblongata; and that this voluntary act disposes the nerves of both medullæ into modes of acting accordant with itself, by means of the chinks or hollows that appear on the back of each, where the fibres of the cerebrum form delicately motive and sometimes even muscular membranes, (for instance, in the acquired habit of speaking, by means of the calamus scriptorius, and the little hollow

in the posterior cervical portion of the spinal marrow, where the two locutory nerves take their rise; namely, the ninth nerve of the head, and the second of the neck). For the fibre of the cerebrum does not go off into nerves, but traversing the two medullæ, disposes the fibres proper to each, to act in a manner most highly accordant with itself. That the voluntary thus passes into the spontaneous natural, the reader will find by a variety of convincing arguments in the Parts on the Brain. If now it be granted that the connexion of the cerebrum with the cerebellum is such as we have stated (n. 572), and that the secondary origin or intermediate cause of these voluntary actions, which are converted into spontaneous actions, is in the medulla spinalis and medulla oblongata, it will follow, that merely from the causes which exist in the body, this animal, or rather now corporeal machine, may be put in motion for a considerable time, and that some functions may be performed which are then purely physical and mechanical, because altogether unaccompanied with sense or will. This is particularly the case when the cerebrum has begun to harden successively from its outer surface, and has in the mean time, by a course of tardy operations, gradually transferred its power of control to the cerebellum and the two medullæ; and consequently also the motion of the heart, which is of itself natural and spontaneous, particularly as long as the spinal marrow lives with the cerebellum; for the cerebellum inspires the nerves of the heart, which also by its own force expels the blood into that circuit which the heart performs through the body, and which excites it to continue its gyre, just as the hand keeps up the rotation of a wheel by successive impulses.

575. And the same may be the case in subjects born without brains; and in insects after their heads are cut off.—The infantile brain, which is usually more tender and soft than the brain of adults, abounds with viscid matter, and does not immediately acquire consistency, or establish a connexion with the appendages and muscles of the body. Sometimes days, weeks, or months after birth the brain has been found to consist for the most part of a kind of fluor, and yet the infant has previously continued to exercise its vital functions, and its face has been of the natural colour. Wepfer mentions the case of a



foetus, which lived sixteen hours, although the whole of its brain resembled a mass of aqueous vesicles or hydatids, except a small portion at the base of the skull, lodged in a hollow in the sphenoid bone, and which portion consisted only of three medullary corpuscles, two as big as kidney beans, and with slender nervous fibres proceeding from them.\* (*Miscell. Natur. Curios. German.*, an. 3, p. 175, 176, obs. 129). Another author speaks of a foetus, which lived for five days, and had nothing but water within the duplicatures of the dura mater, without the least trace of any spinal marrow at all. (*Ibid.*, obs. 42, p. 62). Tyson saw an infant, (according to Ridley, *Anatomy of the Brain*, chap xvii.,) which had no more brain than might lie in the shell of a filbert, the spinal marrow being much larger than ordinary. Manget makes mention of a foetus of nine months, which had only a small fleshy mass for a brain, and a bifid spinal marrow.<sup>x</sup> Littre speaks of a case in which there was not even a spinal marrow. (*Hist. de l'Acad. Roy. des Sciences*, an. 1701, p. 24.) Kerkring tells us of a boy, as well as of sheep, born without brains. (*Spicilegium Anatomicum*, obs. 46.) Rayger mentions a similar circumstance with regard to a little girl. (*Miscell. Natur. Curios. German.*, an. 3, p. 427, obs. 280.) Tulpius tells us of a boy who had five pounds of water in his head, together with a brain indeed, but which had lost the globular shape, and assumed that of a convex arch. (*Observationes Medicæ*, lib. i., cap. xxiv.) Morgagni instances the case of a child which, instead of a brain, had a small soft mass between the two first vertebræ and the occipital bone. (*Advers. Anat.* ii., anim. 35.) And many other examples of the same kind are recorded by anatomical writers.

There are various species of animals, such as most reptiles, conchilia, birds, and aquatic species, which have a small molecule of brain lying within a kind of bony scale, but still placed very high up in the head. Hydras and serpents twist their huge bellies into folds; snails and tortoises carry about their houses of stone; whales cut their way through the waves like ships; while nevertheless such mighty forces, or the action of so mighty

\* Wepfer states that the third corpuscle was situated posteriorly, and that the spinal marrow proceeded from it, and in its course became of the size usual in the foetus.—(*Tr.*)

a machine, seems to be called forth by a mere morsel of cerebrum. Ostriches, which have the greater part of the brain occupied by the thalami of the optic nerves, and which have but a slender head, are yet enabled to raise their bulky bodies to a considerable height. Certain species of brute animals live more in the body than in the brain, and after decapitation move their several members, muscles, wings, &c., crawl and fly to a very great distance, or live their corporeal life for no inconsiderable period: such are flies, and a variety of little creatures of that kind. According to Caldesi, a tortoise continued to move its shell for a fortnight after its head was cut off (n. 385). If the brain of a fowl or other bird be transfixed with a needle, the bird still survives, and is led by its instincts as if it had received no injury, &c., &c.

576. It is beyond a doubt, that the brains may be connected with their medullæ in a variety of ways, and the medullæ with the viscera of the body; nay, that they actually are connected in different ways in every species of animals, and in each individual of every species. This is evident in the first place from comparative anatomy; as from the anatomy of birds, fish, insects, and other creatures; in no two of which do the connections ever appear exactly alike, nor consequently either the forms or actions of these animals; for either the arteries, fibres, and membranes between the cerebrum and cerebellum, and between these again and the spinal marrow, are connected in one animal in a manner different from that in which they are connected in another; or else the marrow is discontinued in respect to its cineritious substance, and continued in respect only to its fibrillary substance. There are in the spinal marrow of the more imperfect animals several molecules or rings of cineritious substance, which serve as so many origins of activity, and succenturiate cerebella (as in the silk-worm); or in place of this marrow, there is only an extremely slender thread, as in flies, &c. But to recount the diversities which prevail in these respects, would be to recount the several species of animals. Hence the cerebellum may be closely connected with the cerebrum, or the cerebrum may be altogether wanting, and in its place a molecule may be substituted in the superior part of the medulla, which is large, bifid, and of diversified character, &c.



In the same manner the formative substance connects the appendages in monsters in various ways, according to the series of contingents, as in the case of the fœtus with two bodies, one grown to the other, two heads with two faces and necks, four arms, a double thorax with a sternum to each; in the case of one twin monstrously grown to the navel and side of the other, having a double head, a single heart, and the private parts grown together; in the case of monsters with a double womb, two vaginæ, two recta, one anus, and fundament. In the case of brutes, as calves and sheep, born with two or three heads, four ears, two tongues, eight feet. The reader may here add the remarks in n. 255. Hence when the cerebrum and cerebellum are deficient, and in lieu we find a molecule between the first cervical vertebræ, the fibres may nevertheless be inspired with their own fluid from these parts so situated, and the blood may be circulated by the medulla; consequently the motion of the heart may be continued, which motion derives its origin simply from the gyration of its own fluid, differently from what takes place with regard to the other viscera of the body, which in order to produce their motion require in addition the contact of harder corpuscles.

577. And finally in persons whose lungs have been long collapsed.—For cases occur, in which after the collapse of the lungs, still the death of the heart does not ensue, as mentioned above, n. 285, 445. There are other cases in which persons have undergone submersion or strangulation, or have suffered from obstruction in the gullet, the windpipe, the bronchia, and the vesicular substance of the lungs; or who to all appearance have been corpses, with their limbs grown rigid, and the lurid paleness of death marbling their skin; who have been laid out upon the bier, and after the last lament of their parents and the close of the funeral rites, have nevertheless risen to life from their coffins, to the inexpressible joy and astonishment of their friends. Now, unless in these cases there had been some vent for the blood through the semiexpanded lobes of the lungs, or through the foramen ovale from the right side of the heart to the left, or through the coronary arteries (n. 445); unless also the brains had conjoined their animations with the pulsations of the heart (n. 285), these resuscitations never could have taken

place. It therefore follows, according to our proposition, that the motion of the heart may be continued for a time without the assistance of any of them ; but this time will be longer or shorter in proportion as the abovementioned bodies are in the series and connection of causes : in fine, just so long as the nervous fibres of the heart can be maintained in their integrity and power of acting, to preserve them in which is the peculiar office of the cerebellum ; and so long as the blood can be poured from the living fountain into the vena cava.

478. *From these grounds, in connection with those laid down in our former chapters, we may infer the cause of the variation of the pulse. The causes of it, in general, are internal and external ; both of which classes may be further subdivided into natural and preternatural. But the doctrine of the pulse is the last that can be given and completed as its importance deserves.* This doctrine is the most important in the animal economy, and cannot be explained in a few words. For since it depends upon the affections and pathognomy of the animal mind, as also upon external causes, and upon the sound or unsound state of every viscus and of the blood,—changed as this state is by natural or preternatural causes,—hence I am not enabled merely by particular experience with respect to the blood, arteries, veins and heart, to venture into this arena. It is a subject which is coextensive with the whole circle of anatomy and pathology, and were I to enter merely upon a brief exposition of its nature, the very brevity would only tend to obscure a doctrine which of all others in the animal economy stands the highest in the scale of dignity, and is almost the only general index of the state of health in the human body. On this subject of the pulse, or of the circulation of the blood, I may repeat the observation already made at the commencement of the work,—that the doctrine of the blood, although the first to be stated, is nevertheless the last that is capable of being brought to completion (n. 1).



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